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Transactions

AMERICAN FOUNDRYMEN'S ASSOCIATION

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Some Principles of Melting Malleable Iron

By H. A. Schwartz*, Cleveland, O.

Abstract

This paper discusses, on a semi-popular basis, the principles which limit the temperature obtainable in a furnace. It gives some of the principles underlying the transfer of heat to the molten metal and discusses the effect of furnace gas compositions on the melt.

1. Unlike the processes of steel melting, those of the malleable industry are intended generally to produce as little chemical change as possible. An exception may exist in the second stage of duplexing. We are thus confronted mainly with problems of the generation and transfer of heat and only secondarily with the unavoidable chemical reactions.

Heat Losses in Furnaces

2. If heat units be liberated inside a closed container, the temperature within rises until the heat is dissipated through the enclosing walls as fast as it is furnished to the interior. The rate of heat loss (per unit area) through a furnace wall is inversely proportional to its thickness and directly proportional to the temperature difference between the inner and outer faces. The inner face will thus strive to rise in temperature until a given wall dissipates heat as fast as heat is furnished per unit area. If, to do so, the inner face gets hotter than the refractories can stand, the wall will grow thinner until a balance is obtained. In all these cases, exemplified by an electric arc furnace, the limit of temperature is determined by the refractoriness of the brick, and the limiting rate of energy input is that which walls of given material and thickness can dissipate. Any attempt to raise the temperature by

* Manager of Research, National Malleable & Steel Castings Co.

Note: This paper was presented at a Session of the Symposium on Malleable Iron Melting at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

thickening the wall or raising the rate of energy input results merely in destruction of the refractory.

3. In fuel-fired furnaces, the "calorific effect" of the fuel sets another limit to maximum temperatures which may be lower or higher than that just discussed. When unit weight of a given fuel is burned with sufficient oxygen, a definite amount of heat is liberated. This heat is imparted to the products of combustion and raises their temperature by an amount calculated by dividing the number of heat units liberated by the product of the mass and mean specific heat of the products. The flame temperature can thus be raised by heating the fuel and air in advance and by minimizing the weight of the products of combustion by avoiding needless excess of air. Since air is about four-fifths nitrogen, which contributes nothing to combustion and must be heated, obviously, burning fuel in pure oxygen produces higher temperatures than burning it in air, hence, the use of oxygen in the welder's torch.

COMBUSTION REACTIONS

4. Since carbon and hydrogen are the source of heat when burning most fuels, one is prone to say that the oxygen supplied should be exactly that to form CO_2 and H_2O from these combustible elements. This is not strictly correct, for flame temperatures have still another limitation which prevents raising them indefinitely by heating the fuel and air. The reactions

$$C + O_2 = CO_2$$

and

$$2\ H_2 + O_2 = 2\ H_2O$$

do not proceed completely to the right in the presence of sufficient oxygen. Water dissociates at high temperature into its elements, and CO_2 into CO and O_2. The expression

$$\frac{P^2_{H_2O}}{P^2_{H_2} \; P_{O_2}}$$

where P with a subscript indicates the partial pressure of H_2O, H_2, or O_2 in the flame, has a constant value for every temperature which decreases as the temperature rises. It is not of interest here to discuss the numerical value of this constant as a function of temperature which is well known. If then

$$\frac{P^2_{H_2O}}{P^2_{H_2}\,P_{O_2}} = k \text{ or } \frac{P^2_{H_2O}}{P^2_{H_2}} = P_{O_2}\,k \qquad (1)$$

it is plain that if we want to have a large proportion of the hydrogen burned we must increase the partial pressure of oxygen, either by an increase in pressure or in the oxygen content of the gas. Since every increment of oxygen adds a little to the completion of the reaction and, hence, to the amount of heat evolved, but adds also to the mass of flue gas and, hence, to its heat capacity, there is obviously an optimum excess of oxygen for maximum temperature.

5. Similar statements can be made for the expression

$$\frac{P^2_{CO_2}}{P^2_{CO}\,P_{O_2}} . \qquad (2)$$

Most fuels contain both hydrogen and carbon and burn to mixtures of CO, CO_2, H_2 and H_2O in which

$$\frac{P_{CO}\;P_{H_2O}}{P_{CO_2}\;P_{H_2}} \qquad (3)$$

is a known constant varying with the temperature.

6. The adjustment of a furnace gas to this equilibrium is quite perfect and this reaction constant, and the carbon-hydrogen ratio of the fuel is a better guide to the moisture and hydrogen content of a flue gas than most gas analyses.

Combustion in Various Types of Furnaces

7. A German investigator has said that combustion takes place as rapidly as fuel and air can mix. In the case of oil or pulverized coal, mixing takes place only as rapidly as the liquid or solid can volatilize from the surface of the particle, or, for fixed carbon, gasify chemically to CO. Combustion rates then depend upon the fineness of dispersion of the fuel.

8. In the old-fashioned hand-fired air furnace, burning lump coal, the function of the fire box was only to act as a crude gas producer, producing coal gas by distillation and CO by the reac-

tion of insufficient oxygen with fixed carbon. The mixture of combustible gases was then burned to equilibrium by air from the top blast.

9. The cupola always contains an excess of coke. Right at the tuyeres, before the air blast has penetrated far, there is temporarily so large an excess of oxygen that the product is nearly all CO_2. As the hot gases move farther in and farther up, this excess of O_2 disappears and the equilibrium constant (2) requires the simultaneous presence of significant amounts of all three gases in relative amounts determined by temperature. As the gases move on still further, the excess of oxygen disappears further and the reaction

$$C + CO_2 = 2\ CO$$

sets in where equilibrium constant is

$$\frac{P_{CO}^2}{P_{CO_2}} . \qquad (4)$$

As the temperature falls, the numerical value of this constant shifts toward lower CO and higher CO_2 values, but the gases are so cold that this reaction does not take place rapidly. Cupola gas, however, will burn with additional oxygen and the heat equivalent to the oxidation of its CO to CO_2 can be thus recovered and imparted, partially, to the blast.

10. In the case of the electric furnace the source of heat is merely the thermal equivalent of the electrical input I^2R when I is the current (amperes) and R the resistance (ohms) of the electric arc and the metal and/or slag layers through which the current passes in the furnace.

TRANSFER OF HEAT TO METAL

11. Having generated heat, we must impart it to the metal. The induction furnace where the heat is generated in the metal is of little practical interest to the malleable founders. The transfer to and through the liquid iron is by radiation, convection or conduction. Radiation, the transfer of heat without contact and without the transfer of any material substance, is important in electric and reverberatory (air) furnaces. The energy leaving a body by radiation is proportional to the fourth power of its temperature and to a constant called emissivity which is specific to each sub-

stance. The heat transferred by radiation from the bottom of an electrode or an incandescent furnace roof to a layer of molten metal is thus proportional to the difference between the fourth powers of the two temperatures, corrected for the respective emissivities. Obviously the cold body gains heat and the hot one loses. The emissivity of most hot gases is poor and, hence, flames must be made "luminous" by carrying glowing particles of solid matter, usually coke, if they are to heat metal by radiation. Evidently, if the heat generated by burning fuel is to be transferred to a bath, the fuel, air and products of combustion must stay in the furnace at least until the reaction is complete (probably somewhat longer) and, hence, there is a relation between hearth volume and rate of combustion of fuel.

12. The transfer of heat within a mass of burning gas is primarily by convection, *i.e.*, by the formation of currents of hot and cold gas tending to equalize the temperature. This is also an important method of distributing heat in a reverberatory furnace bath for the diffusivity of liquid iron, the property by virtue of which the temperature is raised, due to the transfer of energy from one vibrating atom to another, is not very great. This makes it very desirable to have the flame of an air furnace "rub" the surface of the metal, driving it backward with an equivalent forward flow of metal along the bottom promoting a circulation. Those who have had a bung fall into a bath stopping this circulation will appreciate the practical aspects of this matter. In the cupola, there is some heating by radiation in the melting zone, but, very largely, the solid iron is heated by conduction from contact with hot gas and the liquid iron by this and by contact with glowing coke.

SLAG EFFECTS

13. At present, all malleable iron is believed to be melted in acid furnaces. We are then not concerned with the desulphurizing reactions. Unless the CO content of a flue gas be very high (above about 50 per cent CO and 50 per cent CO_2), oxygen or carbon dioxide will convert metallic iron to Fe_3O_4 up to a temperature of about 1290°F. (700°C.). At higher temperatures, either FeO or Fe_3O_4 will be found, depending on the CO content. The equilibria are well understood.

14. While melting down a cold air furnace charge, a considerable amount of liquid oxides is formed by this method which reacts

with the silica of the furnace to form a liquid silicate slag. This slag loses oxygen to any liquid iron with which it comes into contact, forming impure ferrous silicate and oxidizing carbon to CO, silicon to SiO_2 and Mn to MnO, the two latter entering the slag. The slag keeps itself saturated with SiO_2 from the furnace structure, resulting in a roughly constant concentration of something like 50 per cent. In this slag the MnO and FeO are present in chemical combination with SiO_2, and the activity of their oxygen is negligible. Under such slags, white cast iron does not lose much more carbon and silicon.

15. Such loss as there is, is mainly due to the oxidation of some FeO to Fe_2O_3 at the upper slag surface, its diffusion downward through the slag or its transfer by convection and the reduction of this Fe_2O_3 to FeO at the slag-iron interface or surface of contact by C, Si or Mn in the slag.

16. The Mn content of the slag is determined almost completely by the Mn content of the metal, for the expression

$$\frac{(MnO)}{(FeO)\ [Mn]} \tag{5}$$

in which the quantities in square brackets are mol fractions in the metal and those in parenthesis mol fractions in the slag, is constant for equilibrium conditions. It is, therefore, unavoidable that the manganese loss when making high manganese alloys is greater than when making low Mn alloys.

17. At high temperatures the reaction

$$2\ C + SiO_2 = 2\ CO + Si$$

can proceed in either the slag by reaction with coke particles or in the iron by reaction of refractories or minute traces of dissolved SiO_2 with the dissolved carbon of the iron. Since the partial pressure of CO bubbles is of necessity nearly constant at just over atmospheric pressure and the SiO_2 is constant by saturation toward silica, the relation

$$\frac{[Si]}{[C]^2} \tag{6}$$

in the iron should tend to approach a constant value. In the author's experience, however, this equilibrium contributes little or nothing to the malleable melting reactions though it is of importance in acid electric steel practice.

OXIDATION

18. In air furnace duplexing the formation of iron oxides during melting down occurs in the cupola, and the accumulation of slag in the reverberatory furnace is relatively little. Oxidation thereafter, as in batch type air furnace melting, occurs by direct contact of flame and metal on a relatively clean surface. The flame will attempt to adjust itself to a CO_2-CO-O_2 equilibrium with the carbon content of the liquid metal. If made too oxidizing for this equilibrium, it will try to seize carbon; if too reducing, to deposit carbon. The apparent equilibrium composition for ordinary carbon contents and melting temperature represents about 1.1 per cent O_2, 12.7 per cent CO_2 and 3.6 per cent CO, the remainder H_2O and N_2. The presence of CO is an expression of the dissociation of CO_2 at high temperature, plus the equilibrium with the carbon of the iron.

19. It is quite possible that the oxidation of C in the metal involves first the formation of FeO in the bath and then its reduction by C. At room temperature oxygen is diatomic, but it dissociates at high temperatures partially into molecules of one atom. To dissolve in iron and form FeO or CO, only atomic oxygen is to be considered so that the FeO content should and does rise as the temperature goes up, except to the extent that the increased reaction rate with carbon brings it down again. Reaction rates in solution are generally related to temperature by the expression of the form

$$k = e^{\frac{\Delta H}{RT}}$$

where k is a numerical constant measuring the rate, e is the base of the natural logarithm table, ΔH is the heat evolved by the reaction, R the gas constant, and T the absolute temperature.

20. In the final analysis, a reaction between gas and bath involves something occurring at their surface of contact. The quantitative result is therefore dependent on the area and time of contact per amount of reacting substances. Decarburization and similar reactions are thus largely dependent on the bath depth and the time the metal is in the furnace after melting and skimming.

21. We have also to consider that most charges are rusty, most fuels contain hydrogen and most blast air is moist. All this in-

troduces hydrogen or water into the furnace. Hydrogen dissolves in iron as single atoms so that the equilibrium concentration depends on the total hydrogen in the flame, the degree of its dissociation into water and its components and the degree of dissociation of the orthodox diatomic hydrogen into atomic hydrogen, the two latter being determined by temperature. In steel making hydrogen can be removed by oxidation. In malleable melting, not so, for the equilibrium (3) is such that in the presence of white cast iron carbons, not enough oxygen can exist in the metal to remove the small amounts of hydrogen present.

22. The reaction of H_2O vapor with carbon can result in the removal of considerable amounts of the latter element as observed by Bean. The writer once thought that the reaction might be

$$2\ H_2O + 3\ C = CH_4 + 2\ CO$$

both components of water removing carbon. The dissociation constant of CH_4 at melting temperatures is, however, such that only traces of that compound should be present in contact with the elements. The removal of carbon, however, is a demonstrated fact.

23. It has been suggested by Vacher, Darken and others that, in molten iron, carbon may exist partly as the element and partly as the carbide. Presumably some reaction such as

$$Fe_3C = 3\ Fe + C$$

tends to approach an equilibrium. This equilibrium is probably too far to the left for best annealing and a shift toward the right from completeness may be brought about by the introduction of graphitic material, perhaps late in the melting process.

24. The equilibrium conditions for many reactions have been briefly touched upon and others could have been included. It would not be difficult for the physical chemist to prove that the system is "over determined", that is, that there is no combination of compositions which would fulfill all the conditions. This is not unusual in practical problems. Actually there is not time to attain equilibrium for all reactions and only the conditions for the faster reactions are approached. The flame composition is the result of exceedingly rapid reactions and will usually approach equilibrium. The reactions between two layers (or phases) of gas, slag, metal, are usually the slowest and the reactions within a single liquid somewhat faster. It is quite impossible to generalize and this is the reason why the chemistry of melting can not be told in a short and simple statement.

DISCUSSION

Presiding: D. P. FORBES, Gunite Foundries Corp., Rockford, Ill.

Co-Chairman: CARL F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

N. H. SCHWENK[1]: Do I understand, Doctor, that velocity of the flame causes the metal to keep in revolution?

DR. SCHWARTZ: Yes.

F. J. WURSCHER[2]: The Doctor mentioned that he once endeavored to reduce the sulphur to the utmost minimum. What was the reason?

DR. SCHWARTZ: I think we were prompted by the idea that it was a good thing to make very low sulphur material, and we were at the time just beginning to do electric furnace melting. My recollection is that we were doing cold melting at the time. It may have been just after we began to duplex.

We had basic electric furnaces, and I believe it was part of a desire to see just what those units would do. I think that the combination of a contact with steel foundry operations, plus a desire to see the performance of the basic electrics, influenced us.

The result was disastrous because there was no control as to whether the iron would mottle or not. Out of the same hand ladle, I have seen cases where one casting would be clear gray and one clear white. I would not like to give a rigid explanation as to just what produced the effect. After we found that the product yielded lower sulphur than we wanted, we had to add some iron sulphide to produce a minimum of 0.04 per cent.

CHAIRMAN FORBES: Now that you have indicated that higher sulphur is better, do you feel that there is an upper limit at which you might run into trouble?

DR. SCHWARTZ: We have attempted to find such an upper limit because, whenever an unexpected development occurs, in going to processes which produce higher sulphur irons—maybe 0.14 per cent instead of 0.04 per cent—there is a tendency to blame the sulphur. We have, at various times, tried to explain different transient difficulties on the basis of high sulphur, but we have never been able to get anywhere with it. I presume there must be an end to the string somewhere, but we did not get it by the time we reached .14 per cent or .16 per cent, or something of that sort, except that we arrived at some rather accurate figures which seemed to indicate that the manganese sulphide which we formed was equivalent to an equal volume of carbon.

L. J. KELLY[3]: Dr. Schwartz, did I understand you to say that the test you poured showed gray iron and white iron in the same ladle, in the same type of mould?

DR. SCHWARTZ: The same 50-lb. ladle, on the same floor, one after another.

MR. KELLY: What is your explanation of one turning gray and the other white?

---

[1] Cramp Brass and Iron Foundry Div., Baldwin Locomotive Works, Philadelphia, Pa.
[2] Acme Steel and Malleable Iron Works, Buffalo, N. Y.
[3] Fort Pitt Malleable Iron Co., Pittsburgh, Pa.

DR. SCHWARTZ: I do not know. We corrected the condition by raising the sulphur.

MR. KELLY: We have had the same thing occur. In the same kind of mould, at the same temperature, one casting will be all right and the other will not. There must be a reason.

DR. SCHWARTZ: Of course there must be a reason, but I do not know what it is. I am trying to determine it.

RALPH GREENE[4]: When you were carrying your sulphur as low as that, did you quote the balance of the analysis on the metal?

DR. SCHWARTZ: The manganese was brought down to suit the sulphur on the basis of making manganese sulphide, and about 10 points over for the sulphur. The other analyses showed low carbon and moderate silicons. I presume we might have been running about 2.50 per cent total carbon.

C. H. CRAWFORD[5]: Dr. Schwartz, what part does the angle of impingement of flame on the bath play on the circulation of the bath?

DR. SCHWARTZ: It plays an important part. If it is too steep, there is a tendency to splatter; if it is too flat, there is practically no circulation. My recollection is that the angle between the center line of the blast and the horizontal surface of the metal was, perhaps, as steep as 60°, but it might have been 55 or 50°.

CHAIRMAN FORBES: Is that measured from vertical?

DR. SCHWARTZ: From horizontal.

MR. SCHWENK: Over the bridge wall?

DR. SCHWARTZ: Approximately over the bridge wall, and it would hit out over the furnace about 4 ft. Of course, the effective angle is a little different because you have the suction of the air.

W. R. JAESCHKE[6]: Was the 55° angle the angle of the top blast in connection with an oil burner?

DR. SCHWARTZ: In that case, in connection with hand-fired coal. That, by the way, is a point worth considering. If you have both top blasts as a pulverized or an oil burner, you have a blast direction, the direction of your burner, and the suck on the stack. Of course, the ultimate thing is the direction of the resultant which counts.

A. M. FULTON[7]: Can you take any more liberties with the ratio of sulphur to manganese when the sulphur gets up in a high range, or should it be carried at the same relative ratio?

DR. SCHWARTZ: I think you have to run to a little higher excess of manganese. The reaction of manganese with iron sulphide, making manganese sulphide, does not go to completion; it goes to an equilibrium. I would say that you must have more excess of manganese as the sulphur rises.

---

[4] Detroit Brass and Malleable Works, Wyandotte, Mich.
[5] David Bradley Manufacturing Works, Bradley, Ill.
[6] Whiting Corp., Harvey, Ill.
[7] Northern Malleable Iron Co., St. Paul, Minn.

M. E. MCKINNEY[8]: On straight cupola blackheart malleable, where sulphurs run up to as high as 0.20 per cent, we have found, by quite a number of experiments, that you can go down to where your excess is absolutely zero without any detrimental effects, and up to where the excess over manganese sulphide is 0.35 per cent manganese. In other words, any combination between 1.7 times the sulphur in manganese content up to 1.7 times the sulphur plus 0.35 per cent manganese gave no serious difficulty in annealing.

[8] International Harvester Co., Hamilton, Ontario, Canada.

Open-Hearth Furnace For Production of Malleable Castings

By Leo J. Kelly*, Pittsburgh, Pa.

1. The use of the open-hearth furnace as a melting unit for the production of castings to be malleableized was adopted by the several producers of malleable iron in the Pittsburgh district because of the availability and low cost of natural gas and the fact that the manufacturers of open-hearth furnaces and suppliers of the required refractory brick were located in this district.

2. The first concern in the district to install the open-hearth furnace was the McConway and Torley Co. which produced malleable castings for railroad cars, including the automatic car coupler. The next company to equip its plant with open-hearth furnaces was the Pennsylvania Malleable Iron Co. (later the Pressed Steel Car Co.) which also produced malleable iron castings for railroad cars. The Fort Pitt Malleable Iron Co., when it engaged in the manufacture of the malleable castings, also made use of open-hearth furnaces as melting units, and this type of furnace has been in constant use up to the present time.

Open-Hearth Melting Practice

Capacity of Furnace and Fuel Used

3. In our plant, we operate 3 open-hearth melting furnaces having rated capacities of 45, 25 and 20 tons, respectively. These furnaces are acid lined and fired with low gravity fuel oil. While oil is the prime fuel used, owing to its particular property of permitting better control of the high heat energy generated, the furnaces are also equipped to burn natural gas and gas is available as a stand-by fuel.

* Superintendent, Fort Pitt Malleable Iron Co.

Note: This paper was presented at a Session of the Symposium on Malleable Iron Melting at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

FIG. 1—CHARGING AN OPEN-HEARTH FURNACE.

Composition of Charge

4. The charge or stock, at present, is made up of 38 per cent pig iron, 45 per cent sprue, 15 per cent malleable scrap and 2 per cent steel scrap. It is prepared in the yard under a traveling crane and, by means of crane scales and lifting magnet, is carefully weighed and deposited into charging boxes.

Melting and Refining

5. The stock is charged into the furnaces through the furnace doors by means of a mechanical charger which is portable and operates from a traveling crane over the furnace platform. From 7 to 10 hours are required for the charging, melting and refining operations, depending upon the capacity of the furnaces and upon the character and tonnage of the material charged. As soon as the stock is completely melted down, which requires 4 hours in the large furnace and 3 in the smaller units, the slag formation is broken up and the skimming operations follow. From 2 to 3 distinct skimming operations are necessary, depending upon the amount of slag evolved, to keep the bath clean and to maintain a high rate of heat transfer to the metal. A water-cooled skimmer is employed in the operations. There is no form of slag control other than to avoid excessive oxidation and to keep the stock going into the furnace as free as possible from adhering sand and dirt. Temperatures of 3000°F. (1649°C.) in the furnace and 2870°F. (1577°C.) at the spout are desired and are regularly reached.

Composition Control

6. The chemical composition of the melted charge is controlled by the percentage of silicon, phosphorus and manganese in the make-up material and by preliminary analyses which are made one hour and one-half hour prior to tapping. The carbon content is determined by these preliminary tests, and no attempt is made to ascertain the percentage of this element present in the make-up charge. During the period of melting down and up to the time of the first preliminary test, the carbon will drop from 20 to 30 points and the silicon from 10 to 15 points, and during the period of pouring off there is a gradual drop in the carbon content. This drop is compensated for, in a measure, by additions of petroleum coke. Little or no change takes place in the amounts of the other common elements present. Occasionally the percentage of silicon picks up a point or so. As conditions warrant, coiled steel springs, petroleum coke or ferrosilicon, etc., are added during the refining process and while the heat is being poured, in order to insure and maintain the composition desired.

FIG. 2—TAPPING AN OPEN-HEARTH FURNACE.

ADVANTAGES AND DISADVANTAGES

7. The advantages of the open-hearth furnace lie in its ability to permit close control of the chemical composition of the charge during the melting and refining operations and in its ability to produce large tonnages daily over long periods of time before major repairs are necessary. It is common practice, with proper care of the furnace, to melt from 1000 to 1500 heats in a single run, and the volume of tonnage that can be produced depends, of course, upon the furnace capacity.

8. The principal disadvantage is that the furnace must be kept hot over week-ends and during temporary shut-downs. In the past, this necessity caused considerable expense for labor and fuel, but, during the last several years, the expense has been materially reduced through the use of natural gas and low pressure air, the combustion of which permits the proper temperature to be maintained in the furnace during periods of shut-downs at a low cost for labor and fuel. Another disadvantage, incident to malleable practice, is that only 2 spouts can be advantageously used on the open-hearth furnace in taking off the heats. Thus, a relatively longer time is required to pour the iron.

DISCUSSION

Presiding: DR. H. A. SCHWARTZ, National Malleable and Steel Castings Co., Cleveland, Ohio.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

H. M. LANE[1]: Mr. Kelly, how do you take away the iron, with a large ladle or are you tapping continuously?

MR. KELLY: We take part away in 2-ton crane ladles and part in hand shanks and hand ladles. The crane ladles carry the iron to distant points in the foundry and the hand shanks and hand ladles carry it from the large ladles and also directly from the furnaces to the molds. We do not pour continuously.

MR. LANE: My experience was thirty-odd years ago, and my memory is that they didn't shank much from it; they took most of it away in the ladles.

MR. KELLY: Mr. Lane has reference to the practice at the Penna. Malleable Iron Co. during the early days of its existence. Owing to the fact that the open-hearth furnaces at that plant were elevated above the floor level, it was necessary to take the iron away in crane ladles, from which it was poured into the molds by the hand ladles and shanks. In

[1] Consulting Engineer, Grosse Isle, Mich.

our plant the furnaces are located on the floor level, and we take the iron away by the crane ladles and also by shanks and hand ladles. We use insulated crane ladles and transport the iron about 300 ft.

MR. LANE: When using gas, are you making any attempt to regenerate the gas? Is air the only thing going through the regenerator?

MR. KELLY: We do not attempt to regenerate the gas. The primary air is preheated through pipes coiled over the top of furnaces, and the oil is also preheated to a temperature of about 125°F.

W. R. JAESCHKE[2]: I would like to ask Mr. Kelly what the fuel consumption is on the open hearth.

MR. KELLY: I happened to take a record of a recent 6 day period, running two heats in one furnace and one heat in the other. Consumption was 43 gal. per ton melted.

MR. JAESCHKE: Does that include heating over Sunday?

MR. KELLY: That is 6 days casting production against 7 days furnace operation.

MR. LANE: I thought you were heating over Sunday with gas?

MR. KELLY: That is the way we operate over week-ends and during temporary shut downs. We are now operating 6 days a week and the furnaces are kept hot over Sunday with oil.

MR. LANE: I thought it was kept hot with gas in place of oil?

MR. KELLY: We do use gas but it does not pay us to switch over to gas for one day, as at present we are working Saturdays. When we do not work on Saturdays we resort to the use of gas.

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[2] Whiting Corp., Harvey, Ill.

Cupola-Electric Furnace Duplexing of Malleable Iron

By Charles Morrison*, Saginaw, Mich.

Abstract

In the author's discussion of cupola-electric furnace duplexing of malleable iron, he stresses the fact that the electric furnace is not intended to be a means of obtaining any appreciable reduction of carbon in the iron but that it is to be used as a holding furnace. He states that the success of the process depends on good control of the cupola melting conditions and the raw material used. He describes the duplexing process, giving typical cupola charges and touching upon blast humidity control, the hot blast, tuyere design, carbon absorption, the effect of raw materials on the nature of the metal, cupola and forehearth maintenance, metal control, refractory life and maintenance, temperature control and chemical analysis of the iron.

1. In cupola-electric furnace duplexing of completed and arrested anneal malleable cast iron, the electric furnace is not intended to be a means of obtaining any appreciable reduction of the carbon in the iron, as is the case in the reverberatory-type furnace; but rather, to be used as a holding furnace where superheating, refining, and mixing can be done. The greater portion of the success of this process rests with the ability of the user to obtain good control of the cupola melting conditions and the raw material used therein.

Duplexing Process

Melting

2. Melting is done in four 102-in. diameter cupolas, two being used at a time, while the other two are being repaired. They are lined to 78-in. in the shaft, and 73-in. at the bosh, and have a ca-

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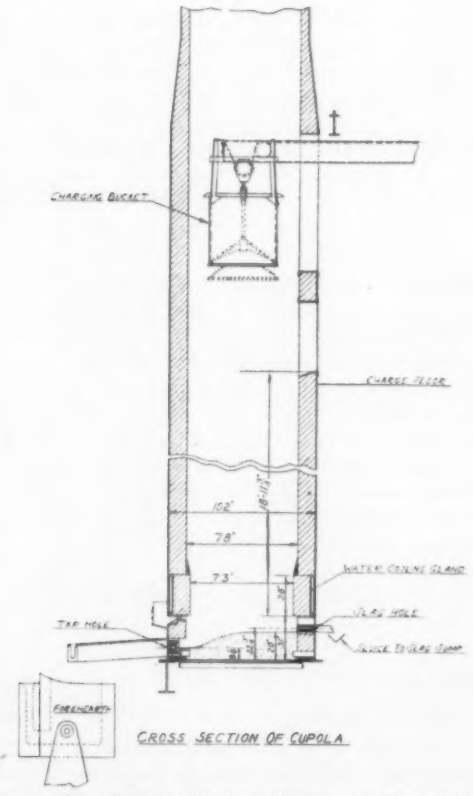

FIG. 1—CROSS SECTION VIEW OF CUPOLA AND FOREHEARTH.

pacity of 30 tons per hour each. The iron is melted continuously for 16 hours from the time the blast is put on until the bottoms are dropped, with the exception of a short time during the lunch period. Each cupola has a 10 ton, oval-shaped, teapot-type forehearth for the storage and mixing of iron. Desulphurizing is done in the forehearth. Figure 1 shows a cross section view of a cupola and forehearth.

Slag Removal

3. Slag is taken off at the rear of the cupola and sluiced with water into a receiving tank, from where it is raised into a storage hopper by means of a bucket dewatering elevator. Trucks then remove the slag from the storage hopper at regular intervals.

Charging

4. Charging is done partially by mechanical means using drop-

bottom buckets and partially from hand trucks. Figure 2 shows the charging bucket being placed in the cupola by the charging crane. The sprue, coke and limestone are charged mechanically; the balance of the charging is done from hand trucks. The charge weighs 10,000 lb. and consists of sprue, silvery pig iron, steel rails, hydraulic steel bundles and miscellaneous steel scrap. A typical cupola charge is as follows:

	Lb.
Rails	1200
Steel Flashings	600
Structural Scrap	400
Hydraulic Bundles	1000
Silvery Pig Iron	1050
Soft Iron Scrap	500
Sprue	5250
	10,000
Coke between charges	900
Limestone	300

FIG. 2—CHARGING BUCKET BEING PLACED IN CUPOLA BY CHARGING CRANE.

FIG. 3—ELECTRIC FURNACE RECEIVING CHARGE OF CUPOLA METAL FROM 3 TON CRANE LADLE.

5. Blower equipment for furnishing blast consists of four blowers, each cupola being supplied by one 10,000 cu. ft. blower, and one 2500 cu. ft. blower, the total blast capacity per cupola being 12,500 cu. ft. Two cupolas can be run at one time.

ELECTRIC FURNACES

6. Two electric furnaces are used for refining and superheating the iron. Each furnace has a capacity of 3 tons per hour cold melt, and 32 tons per hour duplexing. The furnaces are equipped with transformers rated at 3000 k.v.a. with a 40° rise, and 3450 k.v.a. with a 50° rise; however, they are run at about 5000 k.v.a. over a 3 min. period. There are 80-90 volts, and 18,000-20,000 amp. across the arc, with 138-155 volts across the electrodes, depending upon the load, the current being 60 cycle-3 phase. Each furnace has three 12-in. diameter graphite electrodes, the movement of the electrodes being controlled automatically by means of current and voltage coils.

7. The bottoms of these furnaces consist of two courses of fire clay brick, with sufficient layers of ganister fused in to a thickness of approximately 16-in. The sidewalls consist of 13-in. of silica

brick, and ½-in. of silica sand between the sidewalls and the shell. The top consists of silica brick formed on a template with a retaining ring, plugs being inserted at electrode openings. The electrode cable holder, door arches, roof-retaining rings, and electrode glands are water cooled. There is a pouring spout at the front, and a duck bill receiving spout at the rear of the furnace. Tilting is done electrically or by hand. Figure 3 shows the electric furnace receiving a charge of cupola metal from the 3 ton crane ladle. Figure 4 shows a one ton crane ladle receiving iron from an electric furnace.

Operation

8. A bath of 10 tons is held in the electric furnaces. One furnace taps out while the other is heating, thus, a continuous supply of hot metal is available at all times.

9. When about 3 tons of metal have been taken from the electric furnace, additional metal is brought from the cupolas by a 3 ton hot metal crane. Figure 5 shows the 3 ton hot metal crane receiving iron from a cupola forehearth. Approximately 250 lb. of cold steel, in the form of hydraulic bundles, are added to the electric furnace with each charge of 3 tons of cupola metal. Following the addition of the cold metal to the furnace, the iron is heated over approximately a 2 min. period. During the time the iron is being heated in the one furnace, the other furnace is tapping out. The ladles of iron from the cupolas are alternated in such a manner that the same cupola is not sending iron to the same furnace. As a result, good mixing and uniformity are obtained. Figure 6 shows the general layout of the duplexing equipment.

Charge

10. All of the materials going into the charge are accurately weighed. The scales are equipped with recording tape for checking purposes. The scales are checked for no load balance, and with standard weights at the beginning of each shift, and frequently during the day. Figure 7 shows the method of weighing the sprue from the knockout conveyor into the charge buckets. A rough weight is made on the first set of scales and a finished weight on the second scales, the buckets being moved along by gravity rolls. In Fig. 1, a bucket can be seen in the discharging position in the cupola.

11. The order of the charging is as follows: Coke, limestone, pig iron, miscellaneous steel scrap (flashing, briquetted turnings,

rails, structural, etc.), hydraulic bundles, malleable scrap and sprue.

12. The charge is spread uniformly in the cupola. It is desirable to have the charge materials uniform and as small in size as practical. It is also desirable that the level of the charge be kept fairly constant.

13. Referring to the charge, it will be observed that there is a carbon pick-up of 0.77 per cent. There is a sulphur pick-up of 0.048 per cent from the coke, the sulphur at the spout being 0.140 per cent. It is reduced to 0.110 per cent by the addition of from 3 to 5 lb. of purite to the iron stream as it runs into the forehearth. Care must be exercised that cupola slag does not enter the forehearth, or efficient desulphurizing will not be obtained.

14. The oxidation loss is about 0.30 per cent silicon and 0.15 per cent manganese. In our practice, larger losses than this are indicative of poor cupola practice or unsatisfactory raw materials.

15. A typical charge used is shown in Table 1.

Blast Flow to Cupolas

16. There is probably no phase of cupola melting that has been more widely abused than the supplying of blast to the cupola. It is the eternal hope of many foundrymen that if a little more wind is supplied, it will melt a few more tons per hour, even though the cupola is being operated at, or beyond, its theoretical maximum capacity. In the operation of a carbon absorption process, this line of thinking is prone to the production of poor quality metal.

17. The flow of air to the cupolas is controlled by flow meters. The orifice plates for the flow meters are located in the down pipe from the air header to the hot blast stoves. This places the orifice plates on the cold side of the hot blast. The recording controllers are located adjacent to the electric furnaces and cupolas on the ground floor where they are readily available to the cupola operators and the melting metallurgist.

18. In calculating the blast requirements for our practice, we take the following factors into consideration:

(1) That 0.70 to 1.00 per cent of the carbon in the iron, which is the difference between what is charged in and what comes out at the spout, must be picked up by the iron from the coke.

(2) The coke contains a given amount of fixed carbon.

(3) That all of the carbon charged into the cupola either enters the iron or goes out the stack in the form CO_2 or CO.

Table 1

Typical Cupola Charge

Per Cent	Material	Analysis, per cent: Carbon	Silicon	Manganese	Phosphorus	Sulphur	Analysis Going In, per cent: Carbon	Silicon	Manganese	Phosphorus	Sulphur
12.0	Steel rails	0.70		0.80	0.060	0.060	0.084		0.096	0.007	0.007
7.0	Flashing	0.40		0.60	0.050	0.080	0.028		0.042	0.003	0.006
11.5	Hydraulic sheets, structural	0.20		0.40	0.050	0.050	0.023		0.046	0.006	0.006
9.5	Silvery pig iron	2.00	9.45	1.90	0.130	0.015	0.190	0.898	0.180	0.012	0.001
6.0	Annealed scrap	2.40	1.35	0.40	0.070	0.120	0.144	0.081	0.024	0.004	0.007
54.0	Sprue	2.70	1.35	0.40	0.070	0.120	1.458	0.729	0.216	0.038	0.065
100.0	Total In						1.927	1.708	0.604	0.070	0.092
	Out						2.700	1.400	0.450	0.070	0.140
	Change						+0.773	−0.308	−0.154	—	+0.048

Limestone	300 lb. per charge
Coke	920 lb. per charge
Coke Bed Approx.	36-in.
Coke Bed above tuyeres	25-in.
Hot Blast	250°F.
Water in Blast	55 grains per lb. air

(4) All of the carbon charged into the cupola does not necessarily get to the cupola tuyeres due to the secondary reaction: $CO_2 + C = 2CO$.

(5) The amount of carbon that reaches the melting zone to which air must be supplied is the difference between what is absorbed in the iron plus the amount lost out the stack as CO, deducted from the total carbon charged.

19. Figure 8 shows a chart we use for calculating our blast. Experience has taught us that if these figures are exceeded, no faster melting will result and the iron will be oxidized, the amount of oxidation depending upon the extent to which the blast requirements are exceeded. When we change our coke charges, we allow time for the change to reach the tuyeres and then adjust the blast accordingly. This chart is of great value, especially when the cupola is being driven at its maximum capacity.

20. The blast volumes for this chart were calculated as follows: The coke per charge is multiplied by the charges per hour for a given melting rate, to obtain the coke charged per hour. This amount of coke is calculated to carbon by multiplying by the percentage of fixed carbon in the coke. From this figure is deducted the pounds of carbon per hour that are absorbed by the iron from the

FIG. 4—ONE TON CRANE LADLE RECEIVING IRON FROM ELECTRIC FURNACE.

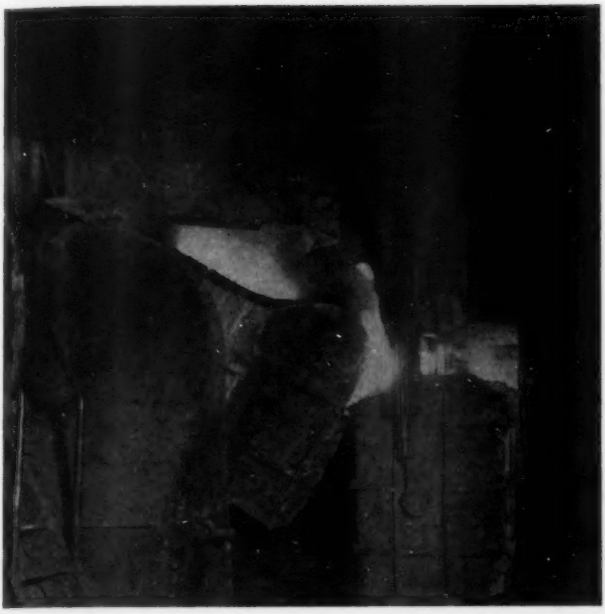

FIG. 5—THREE TON HOT METAL CRANE RECEIVING IRON FROM CUPOLA FOREHEARTH.

coke. The balance is carbon per hour that is available for combustion. This amount of carbon is calculated to be burned to 15.5 per cent CO_2 and 9.5 per cent CO. To the cu. ft. of air for this combustion is added the loss of air through the slag hole. We then have the total cu. ft. of air per hour required, which, when divided by 60, will give the blast requirements per min.

Blast Humidity Control

21. The humidity of the blast is controlled by passing the air through a humidity control unit. This unit, as well as the control equipment for it, is located in the blower room. A wet bulb-dry bulb recorder from which the humidity can be computed, is located in the instrument room near the cupolas and electric furnaces, where it is readily available to the metallurgist. This instrument serves as a check on the functioning of the automatic control equipment. In addition to this, humidity readings are taken inside the blast chamber with a sling psychrometer once each shift, as a further check on the functioning of the humidity equipment. Figure 9 is a simplified psychrometric chart that we use for calculating the absolute humidity of the blast, from the wet bulb-dry bulb recorder temperatures.

22. The humidity control unit is so designed that the blast can be dehumidified in the summer and humidified in the winter. We hold about 55 grains of moisture per lb. of air, or about 4.2 grains of moisture per cu. ft. of blast. This amount of moisture was chosen primarily because the cost of dehumidifying from 4 grains down to dry blast is out of proportion to the benefit derived from it. Rather than vary from 0.6 grains up to 4 grains in the winter, we provided for adding water to the blast during this period to make our operation uniform during the entire year.

23. Prior to the installation of the humidity control equipment, our practice was to take humidity readings each hour and adjust the coke accordingly for carbon control. About 20 to 30 lb. of coke were necessary to compensate for one grain of moisture change in the blast.

24. In addition to the bad effects on the carbon control of the iron, humidity has a very pronounced effect on the mottling tendency of the iron. All other things being equal, the iron made with low humidity blast will mottle much more readily than iron made with high humidity blast.

25. The ability of the iron to anneal is also affected to a marked degree by the moisture in the blast. High moisture in the blast produces an iron that anneals with more difficulty than iron of the same composition made with blast that is low in moisture content.

26. Iron made with high moisture content in the blast has a tendency to shrink and crack worse than iron of the same composition made with low humidity blast.

27. In general, it may be stated that it is desirable to maintain as low a moisture content in the blast as is practical from a cost standpoint. Controlled humidity at a relatively low level is certainly very desirable both from the standpoint of gating and metallurgical control.

Hot Blast

28. The blast is heated by external gas-fired heat exchangers, which are located above and to the side of the blower room. The burner equipment for firing the hot blast stoves for each cupola is actuated by air operated floating control. A hot blast temperature recorder is located in the instrument room where it is available to the cupola operators and the melting metallurgist.

29. The hot blast temperature being used at the present time is

300°F. However, the most desirable temperature to be used will vary from time to time, depending upon a number of factors such as:

(1) Type of coke being used.
(2) Nature of materials being used.
(3) Height of coke bed.
(4) Chemical analysis of the slag.

30. We have operated at various times with blast temperatures of 250° to 425°F., depending upon the conditions encountered.

31. In general, it may be stated that our experience with hot blast is as follows:

(1) Melting conditions in the cupola are much less oxidizing.
(2) Analysis of the iron is more uniform.
(3) Iron made with hot blast anneals with greater ease than iron made with cold blast.
(4) Materials that melt with difficulty such as large bundles, etc., melt with greater ease using hot blast.
(5) Trouble with heavy, viscous slags due to low temperature is practically eliminated using hot blast.
(6) Considerably less trouble from bridging, and slagging of the tuyeres is experienced with the use of hot blast.

32. Going from cold blast to hot blast of approximately 300°F., the coke between charges, as well as the bed coke, must be cut. Approximately 150 lb. of coke less per charge, and 4 to 6-in. less bed height must be used for the same carbon at the spout. The melting conditions using hot blast, however, even though the coke bed is considerably lower, are much less oxidizing than they are on cold blast with a higher coke bed.

33. In using hot blast we have found it necessary to water cool

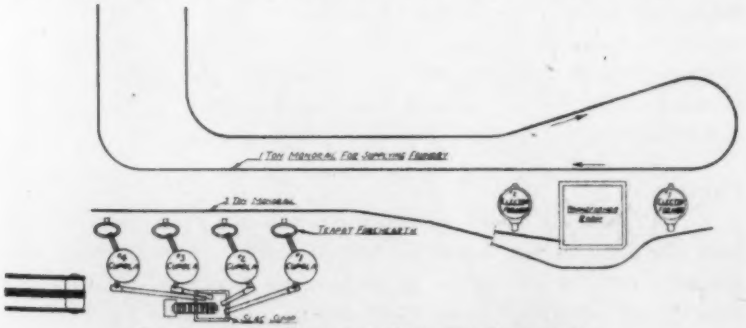

FIG. 6—GENERAL LAYOUT OF DUPLEXING EQUIPMENT.

FIG. 7—METHOD OF WEIGHING SPRUE FROM KNOCKOUT CONVEYOR INTO CHARGE BUCKETS.

the bosh at the shell in order to prevent burning through the shell late in the day. Figure 1 shows the arrangement of the water cooled glands.

34. The question as to why we use an external gas-fired hot blast stove instead of utilizing the carbon monoxide and latent heat in the stack gases for heating the blast will naturally be raised. Gas analysis taken on our cupolas prior to the installation of hot blast equipment revealed that there was not sufficient carbon monoxide present to sustain combustion, and that it would be necessary to enrich the cupola gases with raw gas, oil, or some other hydrocarbon, in order to sustain combustion and control the temperature. Taking all factors into consideration, it was felt that external gas-fired heaters would be most satisfactory.

Tuyeres

35. Practically every metallurgist who has ever operated a cupola has his own pet theory on tuyere design. Consequently, there are any number of tuyere arrangements that can be used on a cupola, all of which have their merits. We have tried various tuyeres over a period of years and finally have arrived at the

arrangement as shown in Fig. 1. These tuyeres are 2½-in. high and are continuous around the circumference of the cupola with the exception of 2½-in. x 4½-in. brick spaced uniformly to support the ends of the upper tuyere plates where they butt together. We have found that this type of tuyere has given us good blast penetration and distribution with our charge.

CARBON ABSORPTION

36. In the making of a low carbon iron in the cupola, where a portion of the final carbon in the iron must be picked up from the coke, the regulation of carbon pick-up to obtain a consistent carbon analysis at the spout becomes a very critical operation, and the success of the melting process rests with the ability to accurately regulate the carbon pick-up. As previously stated, the difference between the carbon going into the charge and the iron at the spout is from 0.70 per cent to 1.00 per cent depending upon the analysis of the charge.

37. There are many factors affecting carbon absorption by the iron from the coke, such as:

(1) Nature of the coke.
(2) Height of coke bed.
(3) Time that iron is in contact with the coke.
(4) Temperature of melting zone.
(5) Temperature of the blast.
(6) Humidity of the blast.

38. Of the various factors enumerated, coke is by far the most important. In view of the fact that the amount of coke used in a process of making low carbon iron is never very great, it is very desirable to use that type of coke which will permit the use of the maximum amount practical for the same carbon at the spout. It is necessary, regardless of the type of coke used, to adjust the coke charges to obtain the correct carbon at the spout. This leaves the process of melting largely at the mercy of the coke.

39. The ability of certain types of cokes to produce low carbon iron is well known. These cokes are known as low carbon cokes, or slow burning cokes. Slow burning coke, by virtue of its inability to give up carbon to the iron, permits the use of more coke for a given carbon at the spout. This is desirable not only from a point of view of improved melting conditions, but also from a standpoint of economy, as it is much costlier to heat the iron in the

electric furnace than it is to produce hotter iron in the cupola by using additional coke, inasmuch as coke costs less per unit of heat than electricity.

40. The height of the coke bed is of major importance. With a given type of coke it determines the carbon content of the metal at the spout. Apparently, the distance which the molten iron must pass through the incandescent coke determines, to a great degree, the amount of carbon absorbed by the iron. Calculation of the bed height is largely a matter of experience with certain types of cokes and materials used.

41. The longer the iron is in contact with the coke, the more nearly the carbon will be to the saturation point. Therefore, it is desirable for low carbon iron to have the iron run from the cupola as fast as it is melted. This is not entirely practical in our case, for reason of slagging, mixing, etc. With intermittent tapping, the

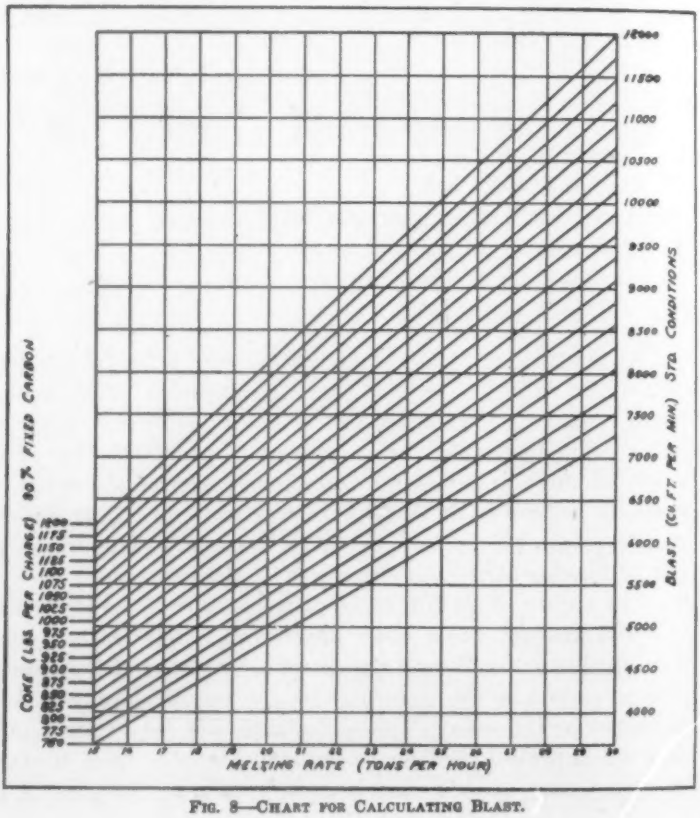

FIG. 8—CHART FOR CALCULATING BLAST.

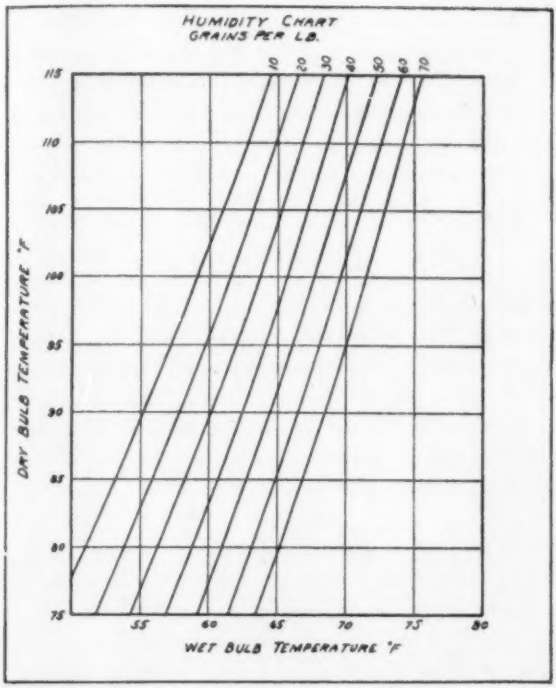

FIG. 9—SIMPLIFIED PSYCHROMETRIC CHART USED FOR CALCULATING ABSOLUTE HUMIDITY OF THE BLAST.

time between taps is determined by the storage capacity of the well, the cupola being tapped when the iron starts to run at the slag hole. We previously used a 6-in. sand bed in our cupolas, which gave a relatively large storage of metal in the well, and consequently a relatively long period in which the iron was in contact with the coke in the well. As we were forced to use raw materials in the charge that were higher in carbon content, structural plate and flashing, etc., in the place of sheet, the amount of carbon to be absorbed from the coke dropped from 1.05 to 0.80 per cent which necessitated reducing the amount of coke used. This disadvantage was largely overcome by increasing the sand bed to 20-in. as shown in Fig. 1. By increasing the sand bed, the storage capacity of the well was reduced, thus making it necessary to tap the cupola more frequently, and consequently reducing the time of contact of iron to coke, thus permitting the use of more coke for the same carbon at the spout.

42. All other things being equal, the hotter the temperature of

the melting zone, the more rapid will be the absorption of carbon by the iron. Hot blast by raising the flame temperature of the combustion gases, thereby increasing the temperature in the melting zone, increases the rate of carbon absorption of the iron. In the previous discussion of the hot blast, we pointed out that it is necessary to use considerably less coke with hot blast for this reason.

RAW MATERIALS

43. The effect of raw materials on the nature of the metal is so pronounced that full knowledge of the characteristics of the raw materials and their effect on the metal must be known if consistently uniform metal is to be manufactured. The characteristics of certain raw materials cannot be melted out in the cupola, consequently, they impart certain peculiarities to the finished metal; thus, it is possible to make several types of iron with the same chemical analysis.

44. Raw material containing graphitic carbons, such as pig iron, annealed malleable, gray cast iron, etc., promote the formation of primary graphite in the white iron castings. Thus, it is necessary to run the carbon and silicon lower than normal to prevent mottling if these materials are used in large quantities in the charge. In some respects this is very undesirable as it increases the annealing time and the metal is more difficult to cast without shrinking or cracking.

45. From a control standpoint, it is essential that the amount

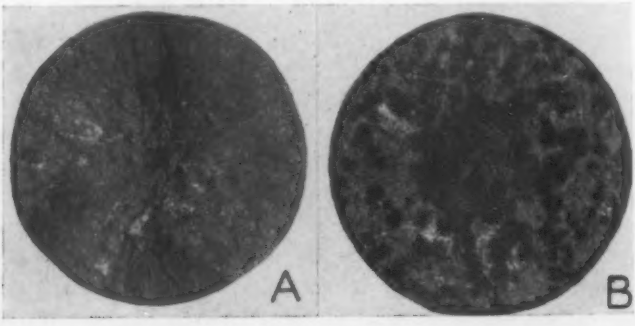

FIG. 10—SHOWING THE EFFECT OF GRAPHITIC MATERIAL IN THE CHARGE. (A) SPRUE ANALYZED 2.68 PER CENT CARBON, 1.42 PER CENT SILICON, 0.42 PER CENT MANGANESE AND WAS CAST FROM METAL MADE WITH 10 PER CENT GRAPHITIC MATERIAL IN THE CHARGE. (B) SPRUE ANALYZED 2.67 PER CENT CARBON, 1.38 PER CENT SILICON, 0.43 PER CENT MANGANESE AND WAS CAST FROM METAL MADE WITH 20 PER CENT GRAPHITIC MATERIAL IN THE CHARGE.

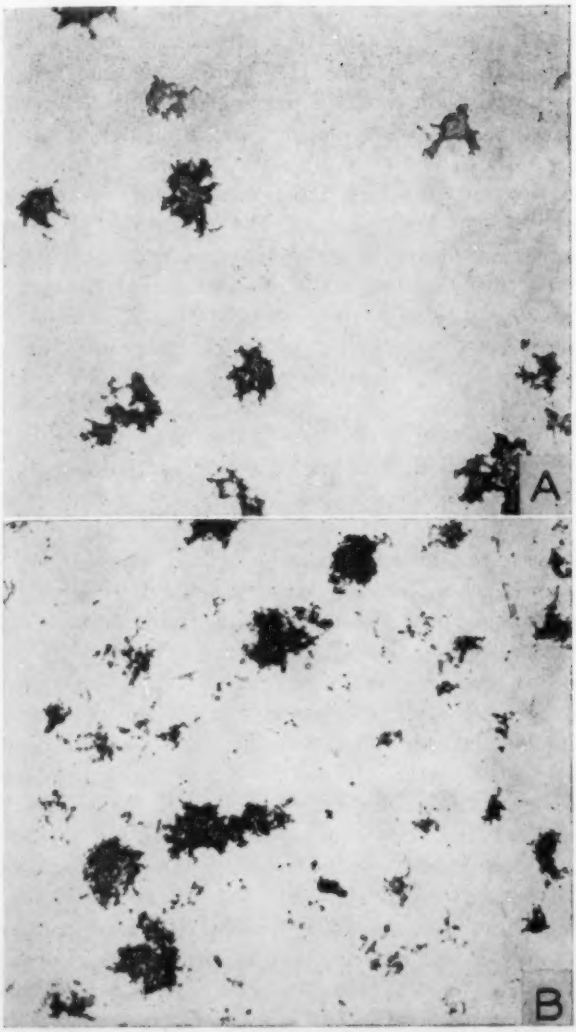

FIG. 11—UNETCHED ANNEALED SPECIMENS OF IRON. (A) MADE WITH 13 PER CENT GRAPHITIC MATERIAL IN THE CHARGE. (B) MADE WITH 26 PER CENT GRAPHITIC MATERIAL IN THE CHARGE.

of graphitic material being charged be well known at all times. In making up the charge, annealed malleable scrap should be weighed up separately from the hard iron sprue for this reason.

46. Figure 10 shows the effect of graphitic material in the charge.

47. The effect of charges high in graphitic material on the iron is manifested in the annealed structure of the metal as well as the white iron structure. Figure 11A shows the unetched annealed specimen of iron made with 13 per cent graphitic material in the charge. Figure 11B shows the unetched annealed specimen of an iron made with 26 per cent graphitic material in the charge. In the latter case, on annealing, the size, distribution, and pattern of the temper carbon is irregular. The formation of innumerable small temper carbon spots between the larger ones forms planes of weakness through the ferrite due to the very short distance between the spots. This type of metal, while it anneals with ease due to the numerous centers of graphitization, is undesirable because of its low strength and poor ductility.

48. Aside from coke, pig iron is the most critical material charged into the cupola. The heredity of the pig iron, as far back as the ores from which it is made, can be carried into the iron in the finished state, even when the pig iron is used in the charge in small quantities.

49. The type of ores used, the coke used in the blast furnace, furnace temperatures, casting practice, etc., all contribute to the production of pig iron having certain characteristics which, in turn, impart certain characteristics to the iron.

50. In one instance, our iron annealed with great difficulty for no apparent reason. On investigation it was found that the steadite in the pig iron had a peculiar shape and distribution. In tracing back still further, it was found that a certain high phosphorus ore was producing this condition. When the ore was eliminated from the blast furnace charge, the pig iron no longer had that peculiar steadite formation, and the iron made using this pig iron annealed satisfactorily.

51. In another instance, pearlitic malleable iron produced from a charge using a small percentage of a certain pig iron showed abnormal bull's-eye structure, and the matrix spheroidized with difficulty. When the offending pig iron was removed from the charge, this condition was eliminated. Figures 12 and 13 illustrate this condition. In Fig. 12 the structure is normal. Figure 13 illustrates an abnormal structure due to abnormal pig iron. Various pig irons melt down in the cupola differently, even though the analysis is the same.

52. The amount and shape of the graphite in the pig iron is important and should be watched, as large flakes and quantities will produce an iron that is very prone to mottle. From this stand-

point, silvery pig iron is more satisfactory than malleable pig iron. Not only is the amount of graphite in silvery pig iron less, but it is of a much finer nature. This condition is illustrated in Fig. 14. Both of these sprues were poured from iron having similar analysis. The sprue shown in Fig. 14A was poured from iron made with silvery pig iron as a silicon base. The sprue in Fig. 14B was

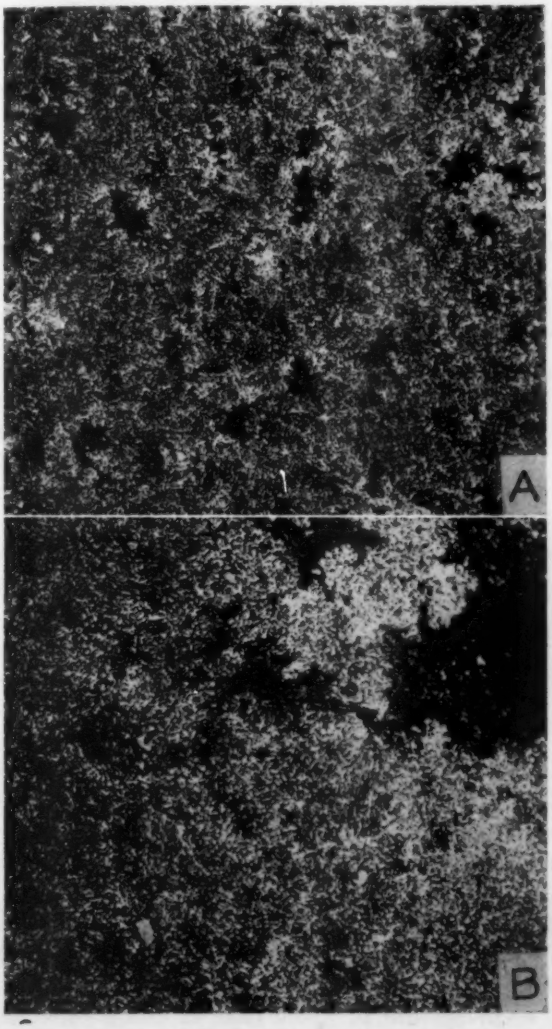

FIG. 12—PEARLITIC MALLEABLE IRON PRODUCED FROM NORMAL CHARGE. (A) x100. (B) x500.

poured from an iron made with a considerable percentage of malleable pig iron used as a silicon base.

53. Our practice is to place pig iron from different sources into separate piles. As a rule, we do not run pig iron from two sources in the charge at the same time. A careful record of the type of pig iron used each day is kept in order that any irregularities in the iron can be traced. Periodic checks are made of the microstructure of the pig iron to ascertain if any changes in structure have taken place.

54. Coke is the most important material charged into the cupola. On the nature of the coke can rest a great deal of the success of the cupola operation, especially in the production of low carbon iron. Aside from the usual specifications for size, shatter, porosity, fixed carbon, volatile ash, etc., the coke should have certain burning characteristics.

55. Coking practice such as washing, grading and mixing of coals, aging of coals, coking temperature and time, etc., determine the burning characteristics of the coke.

56. Not only does the type of coke used determine the amount of coke used, but it also has a bearing on the type of metal produced. Certain types of coke produce an iron that will be very prone to mottle, while others will act just the opposite. Figure 15 illustrates the effect of coke on the characteristics of the metal. Both of these sprues were poured from iron of similar chemical analysis using the same charge. The sprue in Fig. 15A, which is normal, was poured from an iron made with slow burning coke. The sprue in Fig. 15B is abnormal and was poured from an iron made with fast burning coke.

57. Size of the coke is of considerable importance as fluctuations in size will seriously affect the bed height and lead to fluctuations in carbon content of the iron. In preparing the coke bed, we fork the coke and reject any coke that passes between the tines which are 3-in. apart. If this is not done, large variations in the starting carbons will result. The size is also of importance from a standpoint of blast penetration, as fine coke, 3-in. and under, produces high back pressure in the cupola. We have found that 3-in. x 7-in. coke is most suited to our practice.

58. If wet coke is used, due allowance for the water in the coke is made. We have found that a figure of 5 per cent of the weight of the coke works fairly good in most cases.

59. A small amount of green coke or green ends can be very detrimental to the operation as it leads to high and fluctuating

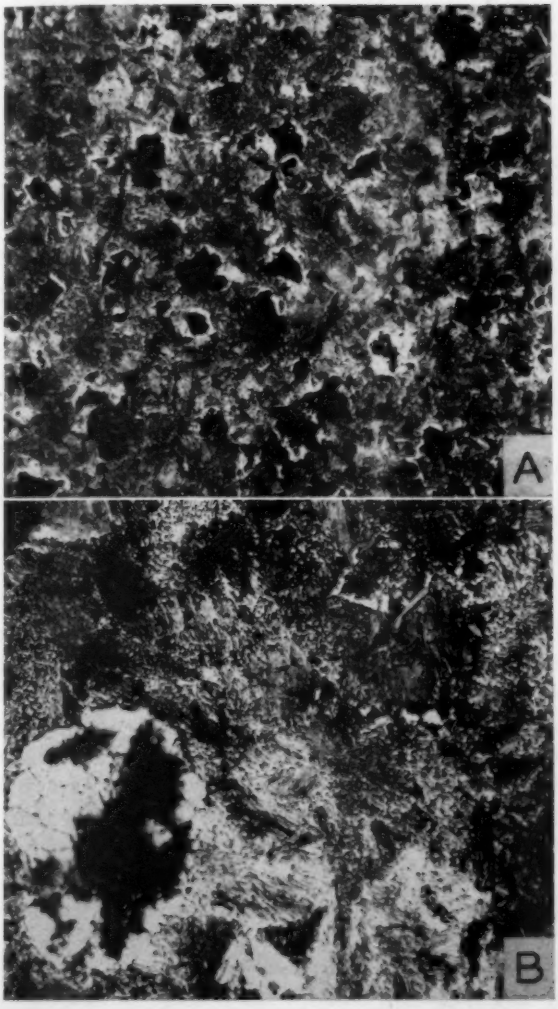

FIG. 13—PEARLITIC MALLEABLE IRON PRODUCED FROM CHARGE USING SMALL PERCENTAGE OF ABNORMAL PIG IRON. (A) x100. (B) x500.

carbons. Extreme care must be used at the coke ovens to remove this material.

60. Rusty charge material is avoided as much as possible. This type of stock fluxes the cupola lining and slag blocks badly, contributes to irregular silicon and manganese analysis, and leads to large melting losses. Moreover, iron made with rusty material

shrinks, misruns and cracks abnormally, and anneals with difficulty. Sprues poured from an iron made with high iron oxide content in the charge will not mottle very easily even with very soft iron.

61. The exact mechanism of iron oxide on the metallurgy of iron is not too well known. In some instances it appears to be beneficial, while in others it is definitely detrimental. However, the outstanding objection to its presence is that the quantity is usually indeterminate, therefore, it introduces a variable that is not readily controllable.

62. A constant watch is kept for tramp materials in the charge, such as gray cast iron, stove plate, aluminum, brass, bronze, tin plate, chrome plate, alloy steel, etc. These materials are thrown out, as they all are detrimental to the metal in one way or another.

63. A rigid inspection is made of all raw materials entering the plant, and chemical analysis is made whenever in doubt as to the type and analysis of the material.

CUPOLA AND FOREHEARTH MAINTENANCE

64 The cupolas are run for about 16 hours after which the bottoms are dropped and the cupolas allowed to cool for repairing the following day. Practically all of the burn takes place from a point just above the upper tuyere plates, extending almost to the top of the bosh. This section is torn out and rebuilt with new blocks, the blocks being laid up with dry joints. After this section is rebuilt, the inside face is washed with a fire clay slurry to seal the cracks and prevent slag penetration at the joints. A good grade of dense, hard-burned, firebrick is used in both the cupolas and forehearths. It is very important that a high grade repair job be done on the cupolas and that dimensions of the tuyeres for spacing, height and diameter be accurately held.

65. In lining the forehearths, the bricks are dipped in a slurry of high temperature fireclay to obtain very tight joints. It is very important that this be done or the basic slag will erode the lining at the joints.

ELECTRIC FURNACE PRACTICE

Metal Control

66. As previously stated, the electric furnaces are not used as a means of producing a somewhat lower carbon iron than is

produced from the cupolas. The electric furnace serves as a superheating, mixing, and refining medium, and acts as a holding furnace so a constant supply of uniform hot metal is available for the foundry at all times.

67. The chemical change in the iron in the electric furnace from that of the cupola metal is slight. The physical change in the metal is considerable. There is a loss of up to 0.05 per cent carbon and 0.05 per cent silicon, with a 4 per cent cold steel addition.

68. Sprues poured from the cupola forehearth iron show considerable primary graphite, and in some instances are almost gray. Sprues poured from the same iron in the electric furnaces, to which cold steel had been added, show considerably less primary graphite. The addition of cold steel, plus holding and superheating, changes the characteristics of the metal to such a degree that it casts white, whereas, otherwise, it would cast partially gray. It is possible by the judicious use of steel to control the mottling characteristics of the metal, without materially altering the chemical analysis.

69. In the event that the carbon or silicon, or both, in the cupola iron are lower than desirable, it is possible to alter the characteristics of the metal in the opposite direction by the addition of silvery pig iron to the electric furnaces. Care must be exercised in the use of pig iron, as too much will promote the formation of carbon nuclei, which results in the formation of excessive primary graphite. The increase of carbon or silicon from the addition of pig iron is not great. However, the effect on the characteristics of the metal is very pronounced. The addition of as little as 0.05 per cent silicon will change the nature of the metal

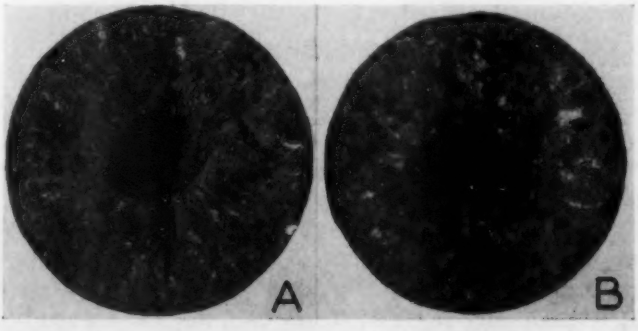

FIG. 14—SPRUES POURED FROM IRONS HAVING SIMILAR ANALYSES. (A) POURED FROM IRON MADE WITH SILVERY PIG IRON AS A SILICON BASE. (B) POURED FROM IRON MADE WITH CONSIDERABLE PERCENTAGE OF MALLEABLE PIG IRON AS A SILICON BASE.

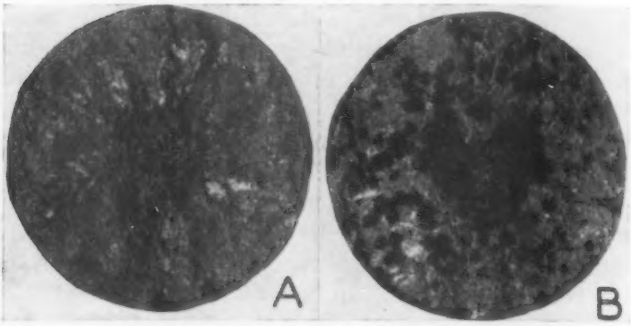

FIG. 15—ILLUSTRATES THE EFFECT OF COKE ON THE CHARACTERISTICS OF METAL. (A) NORMAL SPRUE POURED FROM IRON MADE WITH SLOW BURNING COKE. (B) ABNORMAL SPRUE POURED FROM IRON MADE WITH FAST BURNING COKE.

to a point where it will cast and anneal satisfactorily, whereas, otherwise, it would cast and anneal with some difficulty. However, adjusting the iron in the electric furnaces will not entirely eliminate the bad characteristics produced by incorrect melting in the cupola.

70. Similar to the over treatment with pig iron, the addition of large quantities of steel to the electric furnace is undesirable as it imparts steely characteristics to the metal, thereby making the metal cast and anneal with difficulty.

71. Manganese can be increased by the addition of ferromanganese or manganese briquettes to the electric furnaces. However, it cannot be lowered appreciably by adding steel.

72. The type of steel added to the electric furnaces, of course, is of major importance. The steel should be fairly heavy and free of oil, grease, moisture, or oxide. The addition of rusty stock to the furnaces not only will seriously alter the silicon and manganese content of the iron, but will also introduce hydrogen into the metal.

73. If considerable rusty stock is added and the metal brought to a fairly high temperature, a boil will be produced exactly the same as in the electric furnace steel making. In this event very serious alterations in the metal will take place both chemically and physically.

74. The electric furnace doors are kept open at all times, as we have found that if the furnaces are run with the doors closed, the iron mottles with ease. This phenomenon is not clearly understood. We can only say that it has been our experience that any condition that tends to deoxidize the metal promotes the formation of primary graphite, and any condition that oxidizes the

metal acts in the opposite direction. Operating with the doors closed, the furnace atmosphere is less oxidizing than with the doors open.

Firing of Furnaces

75. Correct firing of the electric furnaces is essential for the production of a uniform metal. The furnace operator must know the temperature of the cupola metal coming over, the amount of steel or pig iron added, temperature of the last tap, voltage available, etc., in order to intelligently operate the electric furnaces. For duplexing 25 to 30 tons per hour in a furnace 45 to 60 k.w.h. will be consumed per ton of iron. For each 3 tons of cupola metal put into the furnace, between 135 to 180 k.w.h. must be put into the iron for melting cold steel, and superheating the iron. With full knowledge of the various factors, plus optical pyrometer readings on the electric furnace and cupola iron, the operator can hold the iron temperature from the electric furnaces within 30°F.

76. Firing should be done at as low an input as possible over the longest period of time available. A minimum of 2 min. is set for the heating and refining period. High inputs over a short period will produce carbon pick-up and also waste electrodes due to absorption in the iron and tearing off of graphite due to high current densities. Normal electrode consumption is from 3.0 to 5.0 lb. per ton. Firing of the furnaces is alternated to keep the demand low.

77. Carbon pick-up is especially vicious, not only because of the carbon increase, but also because the introduction of graphite into the iron furnishes graphite nuclei, thereby promoting the formation of primary graphite. It is essential for this reason to remove any broken electrode from the bath as quickly as possible and take the necessary steps to condition the iron.

78. The bath in the furnace is kept as free of slag as possible. With the high k.w. input necessary to heat the iron over a short period, carrying a slag on the bath would result in serious damage to the roof and sidewalls, due to the inability of the iron to absorb heat through the slag.

79. From the standpoint of economical electric furnace practice, low k.w.h. consumption, low electrode consumption, long life on refractories, and smooth operation, it is absolutely essential that the metal from the cupolas be as hot as possible. It naturally follows that it is desirable to use the maximum amount of coke practical in the cupola for this reason.

Refractory Life and Maintenance

80. With good furnace practice about 5000 tons of iron per furnace roof will be obtained. The sidewalls will have to be replaced at about 10,000 tons of iron. The bottoms are patched, but not replaced. As holes appear in the bottom, ganister and silica sand are placed in the holes and fused into place. At times it is necessary to chip out portions of the bottom where it forms a

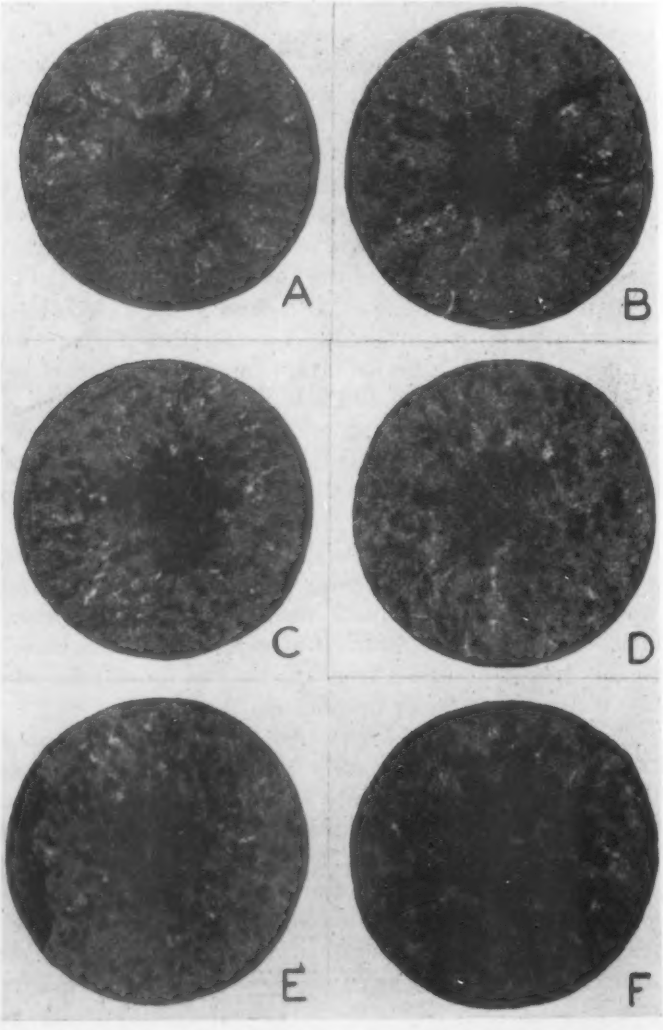

FIG. 16—MOTTLED SPRUES OF VARIOUS TYPES FROM NORMAL (A) TO BADLY MOTTLED (F).

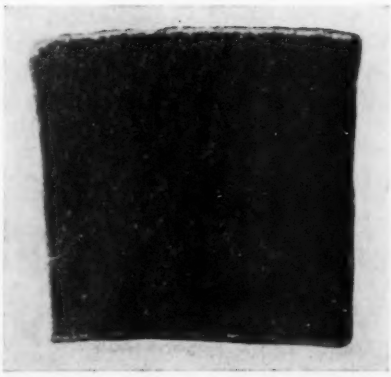

FIG. 17—NORMAL FRACTURE OF IRON TEST BAR AFTER ANNEALING.

junction with the sidewalls and the receiving spouts, inasmuch as sanding tends to build up shoulders at these points, thereby reducing the bath capacity in the furnace.

Test Sprues

81. Test sprues are poured every 20 min. from each electric furnace for the purpose of establishing the tendencies of the iron to form primary graphite. These sprues are 1½-in. diameter at base, 2-in. diameter at top, and 7-in. long. They are poured into a green sand mold, allowed to cool slowly until black, and then quenched in water (for time saving only) and broken. The fracture is then examined for a structure.

82. The size and cooling rate of the sprue is such that it represents a condition that would be somewhat worse, from a standpoint of the formation of primary graphite, than that encountered with the heaviest section jobs being made in production.

83. A great deal can be learned about the nature of the metal from the examination of the fracture of the sprues. The nature of the fractures determines to a great degree the amount of steel that is added to the electric furnaces. The analysis is altered from time to time to produce the desired fracture in the sprues.

84. For good anneal, good fluidity of the metal, and good feeding of castings, it is desirable that the sprues show some mottle spots. Abundant mottle spots in the core indicate high silicon content. A dark rim on the sprue indicates high carbon iron. Figure 16 illustrates sprues of various types, from normal to badly mottled.

85. As a check on the nature of raw materials and their effect on the structure and physical characteristics of the metal, the pouring of test sprues is invaluable. They are also a guide for adjusting melting conditions in the cupola to produce the desired type of metal.

Temperature Control

86. Optical pyrometer readings are taken on the electric furnace iron at the beginning of each tap. Readings on the cupola iron are taken at frequent intervals. The amount of heat to be put into the iron in the electric furnaces is judged from the cupola metal temperatures, rate of production, and the amount of cold steel added to the furnace, etc. A certain amount of good judgment is essential to obtain uniform electric furnace metal temperature. The temperature readings taken on the cupola metal are also invaluable as information pertaining to the operation of the cupolas.

87. Iron taken from the electric furnace is from 2750° to 2800°F. The cupola metal at the spout is about 2680° to 2760°F. This temperature will vary depending upon the amount and type of coke being used.

88. We use the disappearing filament type optical pyrometer. We have three of these instruments, one master pyrometer, which is kept in the laboratory, and two service instruments. Of the two service instruments, one is used and the other is kept in the laboratory ready for use in case trouble develops with the other.

89. The service opticals are checked against the master at frequent intervals, using a standard strip filament lamp as a temperature source. Occasionally the instruments are returned to the factory for inspection and checking.

90. Considerable skill is required in obtaining correct temperature readings on molten metal. Where the instrument is calibrated for molten metal in open air, care must be taken to avoid black body conditions, such as reading a stream where the interior of the ladle forms a background for the stream, reading metal partially inside the furnace, etc. It is also essential that dust, fumes, etc., be avoided. In reading the stream of metal, the dark portion of the stream is iron, the brighter portion being iron oxide film or slag. Inasmuch as iron oxide film and slag have a much higher emissivity than iron, readings taken in the bright portion of the stream will be too high.

91. Good pyrometer practice is absolutely necessary for the production of uniform metal. Temperature control is especially essential on the electric furnaces if low power consumption, low

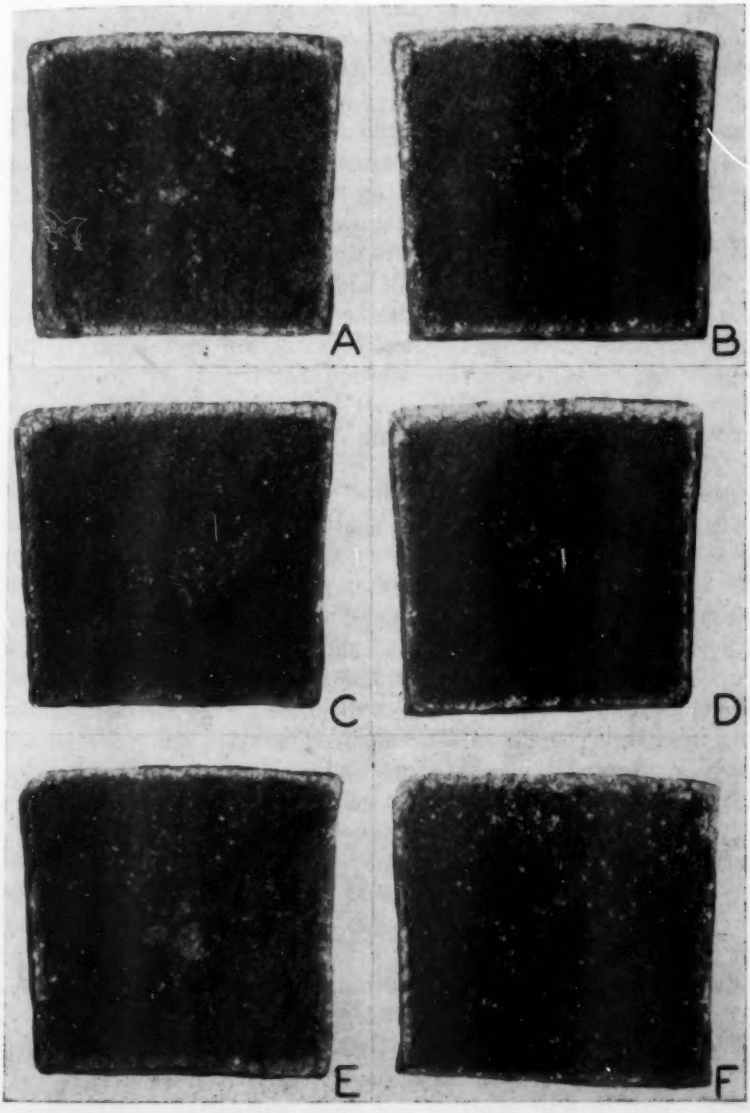

FIG. 18—(A) THROUGH (F) SHOW FRACTURES OF ABNORMAL IRON TEST BARS AFTER ANNEALING.

electrode consumption and long refractory life are to be expected.

Test Bars

92. Every half hour throughout the melt six bars, 7/8-in. sq. x 7-in. long, are cast. These bars are marked with the day of the year, and numbered consecutively from one up, to establish the time of the day at which they were cast. At the end of the day these bars are collected and one complete set is put through each of the annealing kilns. After being annealed, the bars are broken and the fracture examined. Any irregularities in the raw material, melting practice or annealing practice can readily be detected. For tracing the effect of certain raw materials and practice on the ability of the metal to anneal, these bars are invaluable.

93. These are also a valuable aid in checking the operation of the heat-treating furnaces. In the operation of an atmosphere-controlled, heat-treating furnace, they furnish useful information regarding the control of the atmosphere. Figure 17 illustrates a normal fracture. Figure 18 illustrates various types of fractures of abnormal iron, each type being due to a different reason.

Chemical Analysis

94. A sample for chemical analysis is taken from the forehearth iron from each cupola every half hour. These are analyzed for carbon, silicon, and manganese. Samples are taken from each electric furnace every two hours. These are analyzed for carbon, silicon, manganese, phosphorus, and sulphur. Samples of the cupola spout metal are taken a few times during each day. These are analyzed for sulphur to check the efficiency of the desulphurizing practice. The electric furnace iron samples are run each day for chromium as a check on raw material practice. On occasions, nickel, copper, and molybdenum content are also determined.

95. A great many analyses are made on the raw materials entering the plant. This is especially essential at this time in view of the scrap situation, inasmuch as the amount of residual alloy in the steel is increasing. There is also considerable tramp alloy in the scrap. Sizes and shapes of the offending material must be established in order that this material can be sorted. A great deal of old Bessemer rail is being taken up throughout the country. This material must be identified and used with care if the phosphorus and sulphur content of the iron is to be controlled.

96. Cupola slag analyses are made periodically to check the cupola melting and charging practice.

The Use of the Metallurgical Microscope

97. Constant use of the microscope as a check on practice, and the effect of raw materials on the practice, cannot be stressed too greatly. Chemical analysis, while it is positively necessary, does not tell the entire story of the iron. As previously stated, it is possible to make, with the same process, several types of iron with the same chemical analysis. The difference in these irons sometimes can be determined only through the use of the microscope. Change in physical properties of the metal sometimes can readily be explained through the microstructure. Raw materials that on the basis of chemical analysis would appear to be satisfactory may prove to be otherwise under the microscope.

CONCLUSION

98. In cupola-electric furnace duplexing, as in other types of duplexing, good control of the melting practice of the primary melting furnace is absolutely necessary. While certain alterations in the chemistry and physical characteristics of the iron can be made in the holding furnace, in general, it may be stated that the quality of the iron will be determined by the raw materials charged into the cupola and the conditions of melting therein.

99. The electric furnace in many respects is an ideal holding furnace. Rapid superheating without materially altering the chemical analysis of the metal is possible. Alteration of chemical analysis and characteristics of the metal, if desirable, can be accomplished with ease to a certain degree.

100. Cupola-electric furnace duplexing has proved to be a very satisfactory method of supplying the foundry with a constant source of uniform, high-grade metal.

DISCUSSION

Presiding: DR. H. A. SCHWARTZ, National Malleable and Steel Castings Co., Cleveland, Ohio.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

MILTON TILLEY[1]: In arriving at your air-coke chart, did you take into consideration the carbon dioxide that comes from limestone in gas analysis?

MR. MORRISON: Yes, the per cent carbon dioxide from the calcining of the limestone is deducted from the total carbon dioxide in order to calculate blast requirements accurately.

[1] National Malleable and Steel Castings Co., Cleveland, Ohio.

MEMBER: Why is the relatively small amount of steel added to your electric furnace?

MR. MORRISON: Because a small addition of cold steel scrap will change a metal, that otherwise would cast grey, into a metal that will cast white. It imparts steely characteristics to the iron which it otherwise does not possess.

CHAIRMAN SCHWARTZ: Does anyone wish to go back to Mr. Morrison's paper for discussion?

W. R. JAESCHKE[2]: Mr. Morrison shows a 2½-in. tuyere. Was it possible to use that small a tuyere on a cold blast cupola?

MR. MORRISON: Yes, we carried our tuyeres height all the way from 8-in. down to 2-in. on cold and hot blast, with, I would say, almost equal success. However, with 102-in. diameter cupola, having about a 2½-in. tuyere, the best blast penetration is obtained for the type of charge we are now using. The height of the tuyeres, to some extent, will vary with the nature of the raw materials.

MR. JAESCHKE: You did not have any bridging difficulties on cold blast with that size of tuyere?

MR. MORRISON: I would not say that, but on the hot blast we do not have any bridging difficulties. Anybody operating a cold blast has some bridging difficulties.

FREDERICK WURSCHER[3]: For the purpose of comparison, I would like to know the physical properties obtained on normal iron.

MR. MORRISON: I think there is too much worrying done about the physical properties of iron, with too little worrying done about the quality of the castings. Anybody can make a test bar, but it takes a good foundryman to make a casting.

M. E. MCKINNEY[4]: Nevertheless, it is too bad that they are bought on the basis of a test obtained from a test bar.

CHAIRMAN SCHWARTZ: That is relatively more stringent at the present time than otherwise.

MR. MORRISON: The physical properties of cupola duplexed malleable iron are much higher than most people think.

MR. WURSCHER: Do you make it a practice to check periodically on physical properties?

MR. MORRISON: Certainly; we are making all of our castings to Government specification.

MR. WURSCHER: What is that specification?

MR. MORRISON: Grade "B" malleable iron specification.

CHAIRMAN SCHWARTZ: You mean 32510?

MR. MORRISON: Yes.

MEMBER: With hot blast, what is the iron to coke ratio?

MR. MORRISON: The coke ratio will vary, depending upon the nature of the coke, but, generally speaking, it is about 10½ to 11 to 1.

MEMBER: Your melting rate, then? What is the size cupola?

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[2] Whiting Corp., Harvey, Ill.
[3] Acme Steel and Malleable Iron Works, Buffalo, N. Y.
[4] International Harvester Co., Hamilton, Ontario, Canada.

MR. MORRISON: The cupolas are 102-in. in diameter, and the melting rate is 30 tons per hr.

MR. MCKINNEY: What is the ratio of area on this tuyere to the inside area of the cupola?

MR. MORRISON: Offhand, I cannot tell, although I could figure it out, but 2½-in. high by 73-in. across would give a basis for calculating the tuyere area.

MR. MCKINNEY: Our experiments confirm what Mr. Morrison says. It is a mistaken idea that the tuyere has to be ¼ or 1/5 of the inside area of the cupola because, really, that is not the bottleneck. We have found that there is no choking of the blast down to 1/15 of the area, cross-section of the cupola, and usually 1 to 10 on cupola malleable is about the best ratio.

MR. WURSCHER: Has it been your experience, in changing to dehumidification or humidification, as the case may require, that certain foundry defects, which are attributed to water in the air, or atmospheric excess of moisture, have materially decreased since you have this equipment?

MR. MORRISON: I would say definitely that an iron melted with a high humidity in the blast—for instance, in the summer time—shrinks much more severely, hot tears worse, and strain cracks much worse. An iron made with a high humidity in the blast will cast white, even with a very high carbon-silicon total. I have seen iron that had a 4.50 per cent carbon-silicon total cast absolutely white in a 2-in. section with 12 grains of humidity in the blast.

MR. WURSCHER: From the standpoint of economy and a sales proposition, you say it can be stated that savings occurring, due to the avoidance of casting defects, would justify the installation?

MR. MORRISON: I think that many of the things that have kept the foundrymen, as a whole, from producing and controlling a uniform metal, cannot be justified on an actual dollars-and-cents basis.

Most of the things which have been done in the foundry industry, to get control of the product, such as hot blast, refrigerated blast, or humidity control, air flow, etc., have to be done on just good common sense and nothing else. However, there is a distinct saving there that is intangible.

The annealability of the metal is much improved over what it would be with a blast that has no humidity control. I think some of the troubles that air furnace people have with air furnace iron can be attributed to the humidity in the blast being supplied to burn the powdered coal or the oil, whichever the case may be.

K. H. HAMBLIN[5]: Do the gentlemen who make cupola malleable contend that a property which is not measured by the specifications—that is, the resistance to impact—is the equivalent in 32510 cupola malleable with your castings, as compared to test bars?

MR. MORRISON: We have a number of impact figures, but we have

[5] General Fire Extinguisher Co., Providence, R. I.

millions of parts in service that have replaced alloy steel. These parts have been tested at 50° below zero, and they are in machine guns, tanks, and different Ordnance equipment being used today, with relatively few failures. To me, that is the criterion as to the quality of the metal, and not what you get on a test bar.

The thing that I am trying to imply is this: If castings from various producers were tested under a given set of conditions, I think you would find a wide variation in their ability to stand up, regardless of the physical properties obtained on the various test bars.

MR. HAMBLIN: As far as your machine gun parts and tank parts are concerned, are you speaking of a normal malleable iron or are you speaking of a pearlitic malleable? There is a decided difference.

MR. MORRISON: I am speaking of parts made from both malleable iron and pearlitic malleable. They are both made from the same base metal.

MR. WURSCHER: In answer to Mr. Hamblin's question, I do agree that there is a difference between quality as expressed by test bars, which are made under specific requirements, and the metal cast in a casting. However, if the casting is badly molded, badly poured, and results in a defective casting, that is one issue. Nevertheless, the metal in it may be perfectly all right.

If you go to the trouble, having a casting of sufficiently large cross-section which permits the machining out of a test bar, and make that test bar and find that it comes up to the specification required, you may feel quite certain that the metal used and the casting produced therefrom must be satisfactory.

MR. HAMBLIN: My point is this—the ultimate strength, yield point, and elongation do not measure resistance to impact by any manner of means, and I believe that malleable iron castings, poured from iron which meets the specifications or exceeds the specifications 35018, will have a greater impact value than iron which does not meet those specifications.

MR. MORRISON: In answer to Mr. Hamblin's question, the impact tests we have run on cupola-electric-furnace-duplex metal measure up very well with any of the figures we have available on impact tests on various other kinds of malleable iron.

Beyond that, the only other answer is to subject the casting itself to actual service; if it stands up in service, it cannot be very bad.

MR. MCKINNEY: I do not like to see this unfavorable reflection given to test bars because, if we had to test castings with a sledge hammer, we wouldn't have any to use afterwards. We must have some means of evaluating the casting. Naturally, the test bar does not indicate the value of the casting but the value of the metal. You can make a bad casting out of good metal, but you cannot make a good casting out of bad metal.

MR. HAMBLIN: I was not casting any aspersion upon the use of a test bar—it is the only means we have for evaluating the quality of the metal. I merely wanted to point out the fact that, even though your cupola malleable meets the 32510 specification, I still do not believe it

has the resistance to impacts that a metal meeting the other specifications will have, and it is not the difference in the elongation which measures that.

MR. MCKINNEY: No, but I can state that a large number of tests have been made to show that, whether the malleable is made by the cupola process or by the air furnace process, if it meets the 32510 specification, it will give identical impact values as shown by the Izod or Charpy tests.

MR. HAMBLIN: The Izod and Charpy tests are not satisfactory for cast materials. That is the unfortunate part of it. The wedge test is the only one which I know of that gives comparative results, and it has no value except as a comparison of one heat with another.

CHAIRMAN SCHWARTZ: It does seem to me that our problem, in the malleable industry, is to develop some form of impact which can be used to evaluate the impact value of the metal.

DAVID TAMOR[6]: I can say something about the wedge test. On a low carbon iron, if we were to call 2.15 per cent carbon low, it is possible to get 18 to 20 per cent elongation and yet get wedges that may break in two or three blows. With silicon in the neighborhood of 1.15 per cent with that carbon analysis, wedges, as a rule, will curl up without breaking. Considering what has been said, it is very possible to introduce reverse stresses and thus break the wedge.

We place a good deal of faith in the wedge test and look for hairline cracks as the wedge curls over. We record the number of blows before the limitation of the vise is reached. The cracks and breaks are a good indication of impact resistance, and in 75 cases out of 100 there is no sign of a crack. We have, however, found no definite correlation between test bar and wedge impact. In cases where the iron is just on the edge of a frame, it is very possible to meet elongations and strengths of the 35018 grade, get a silky fracture, and still have the wedges go in two or three blows.

MR. MORRISON: Just to be sure that there is not any misunderstanding in regard to my attitude on test bars, I want to make it clear that I did not mean to imply that a test bar is not perfectly all right. As a metallurgist, I insist that, if I make good iron which will pull up on a test bar, part of my job is finished because from there on it rests with the ability of the foundryman to cast it into a mold and to make a casting with it.

However, as a foundryman, I have seen too many instances where the best of metals do not produce a casting that measures up to the quality of the test bar. That is what prompted the statement regarding test bars.

[6] American Chain Malleable Foundry, York, Pa.

Control of Powdered-Coal-Fired Melting Furnaces

By J. A. Durr*, Albion, Mich.

Abstract

The fundamentals of the burning of powdered coal and of combustion are discussed. The author stresses the need for standardizing melting practice to meet present-day specifications and recommends frequent checks to insure uniform practice, giving suggested order of standardization.

1. Before considering melting furnace operations, it would be well to consider some of the fundamentals of the burning of powdered coal.

2. To be classed as a fuel, a material must be able to give out more heat than it receives. No fuel will burn until its particles are brought to this self-supporting condition by the heat absorbed from particles previously burned. Not only this, but the oxygen of the air must be heated likewise to a combining temperature, which involves heating the accompanying nitrogen. This heat must be passed from substance to substance in increments small in themselves but collectively as large as the occasion demands.

3. In the use of powdered coal, the fuel is already prepared for the absorption and evolution of heat. In addition it is aimed to prepare the air, by a practically similar subdivision, for joining in the process. The delivery of coal and air to the furnace must be controlled so that the proper amount of each will be secured.

Combustion

4. In the sequence of events in combustion, the volatile elements of the fuel are first disengaged. These highly combustible hydrocarbons combine with the oxygen of the air, burning to CO_2

* Albion Malleable Iron Co.

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and H_2O and disengaging heat enough to bring the fixed carbon components up to an ignition temperature.

5. It is evident that comparatively large masses of fuel supplied with large volumes of air will, for reasons simply mechanical, fail in efficiency. This is more particularly the case when large contents of volatile matter are suddenly set free by contact with another mass of incandescent fuel and with heated surroundings. Under such conditions it is impossible to get the best results from any fuel. The sweeping off of volumes of volatile gases by large volumes of insufficiently heated air produces smoke. This smoke represents but a small weight of carbon unburned, but may indicate a condition under which a large quantity of gases pass off uncombined. A heavy draft pressure accentuates this condition, and records are plentiful of the passage through fires of large excesses of oxygen which have failed from lack of heat preparatory to combination.

6. A pulverized fuel, the particles of which are each surrounded by a minute envelope of air, thoroughly sufficient to burn them, is an ideal fuel under ideal conditions. In projecting a cloud of such fuel into a highly heated furnace, each particle because of its opacity becomes an absorbent of heat, radiating not only from the furnace walls, but from each neighboring particle as it "inflames." This inflammation progresses with rapidity almost inconceivable. Pulverized fuel injected with its air supply at a speed of several thousand ft. per min. inflames right up against the burner nozzle, the flame playing about its mouth. This is best accomplished by avoiding high pressure in projecting the fuel. The final combination of air and fuel occurs at the instant of projection into the furnace. The air carrying the fuel expands as soon as it is heated. This expansion is, of course, due to the increase in temperature and explains the large volume assumed by the flame on leaving the point of entrance.

7. To burn powdered coal successfully, it must be burned while in suspension in the air. In such a position each particle is surrounded by air which supports the combustion.

8. Contact of the particles of coal dust with other bodies results in the lowering of temperature to such an extent as to make combustion impossible. There is a more or less complete loss of any fuel which falls down to the furnace bottom. The time for combustion is evidently increased as the size of the dust particle is increased, from which it follows that the finer the pulverization,

other things being equal, the quicker and more perfect will be the combustion.

9. The perfect combustion of one lb. of carbon demands 2⅔ lb. of oxygen. This is contained in 11.6 lb. of air, or about 154 cu. ft. Should less than this quantity of air be supplied, a proportionate amount of fuel will be burned to CO with a loss of ⅔ of its potential efficiency. A part of this loss may be regained by contact with heated oxygen, or the CO may pass on and burn in the stock, doing no good. Carbon monoxide is necessarily formed in an atmosphere of gases deficient in oxygen, and its formation renders still more difficult the further establishment of active combustion.

HIGH TEMPERATURES ATTAINABLE

10. The temperatures attainable with powdered coal are very high as indicated by examination of Table 1 which shows the temperatures attained in the perfect combustion of pure carbon with varying amounts of air.

Table 1

TEMPERATURES ATTAINED BY PERFECT COMBUSTION OF ONE POUND OF CARBON WITH VARYING AMOUNTS OF AIR

	Air, lb.		*Temperature, °F.*
One Pound of Carbon with	11.6	Normal	3990
	12.76	10 Per Cent Excess	3747
	13.92	20 Per Cent Excess	3526
	15.08	30 Per Cent Excess	3333
	16.24	40 Per Cent Excess	3153
	17.40	50 Per Cent Excess	3002

11. In practice, the furnace man soon becomes educated to the point of judging whether a fire is hot enough by its color and by the length of the flame. The more perfect the conditions, the shorter and whiter the flame.

12. Some fuels can be burned almost without care on the part of the operator, but powdered coal is not one of these. Fires may run all day with no change in adjustment whatever, but someone should always know that they are right, and the fire should be looked after every half hour or so. A wrong adjustment of either coal or air soon makes itself apparent. Powdered coal burns best with a supply of 200 cu. ft. of air for each pound. It can burn and burn clearly, with 160 cu. ft. and even less, but the excess pays.

When the supply exceeds 200 cu. ft., efficiency begins to fall. There is a noticeable loss even at 208 cu. ft. The eye cannot discriminate between a 200 and a 208 cu. ft. fire, but it can recognize a 250 cu. ft. or even a 220 cu. ft. flame. There is a marked change in the appearance, and unless a "cutting" fire is really wanted there is no excuse for such bad mixture.

STANDARDIZING MELTING PRACTICE

13. To obtain the required uniformity of metal composition which is necessary when meeting present-day specifications for malleable iron, all phases of the melting unit should be standardized. If this is not done, it will not be possible to fire a furnace on the same schedule at all times. If the furnace is not fired on the same schedule, the composition of the metal from heat to heat and day to day is not going to be uniform without excessive doctoring of metal in the furnaces. Unnecessary doctoring in the air furnace should be avoided. Standardizing of melting practice should be done in the following order and frequent checks made to insure that the practice is kept uniform.

Coal

14. The type of coal to use is dependent on geographical location of the plant to the coal fields, size of furnaces, type of stack, whether direct or by underground flue and whether using preheated secondary air or secondary air at room temperature.

15. The writer's experience indicates that when the furnace length between bridge walls does not exceed 30 ft., a coal with 18 to 20 per cent volatile matter gives the best result.

16. Regardless of the kind of coal used, check analysis for sulphur, ash and volatile combustible should be determined on each shipment. Coal with a sulphur in excess of 1.10 per cent and ash in excess of 8 per cent should be rejected.

Coal Preparation

17. There are two customary methods of coal pulverization. Central system and unit system, with various types of pulverizers. The main problem herein lies in coal fineness, uniformity of coal fineness over long periods of time and delivery of the coal to the furnace burners. Considering the nature of the fuel as covered earlier in this paper, it is the writer's opinion and experience that best results are obtained when the coal fineness is kept near 85 per cent through the 200 mesh. Screw feed for delivering the

coal is desired and will pay dividends. Belt feeding does not supply a uniform amount of coal to the burners.

Furnace Design

18. *Burners:* Furnaces can be fired with one or two burners. The main problem is that of obtaining a uniform and intimate mixture of air and coal as the mixture leaves the burner. The burner position in relation to the furnace bottom is important. In general the burners are arranged so that they enter the furnace at a 21° angle, the flame of the two burners converging so that the flame hits the furnace bottom at the center of the furnace, at the first tap holes, approximately 8 ft. from the burner. By the first tap holes, the writer refers to the tap holes on each side of the furnace nearest the burners. The lighting door is usually on the side of the furnace just ahead of the burners.

19. The writer's experience indicates that for greatest efficiency, the burners should be set at an angle of 10° to 11° with the flame converging and hitting the furnace bottom 6½ ft. from the burners. The writer also prefers lighting doors directly under the burners with burners that can be adjusted to any angle during the melting of the heat.

20. *Furnace Bottom:* Furnace bottoms are made from washed silica sand. In some cases, a lower fusion point sand is used on the rear bridge wall. If the washed silica sand is used on the rear bridge wall, it is sometimes necessary to use a clay slurry as a binder to aid in holding the sand in position. The furnace bottom should be made in a furnace by first leveling off, using a template with a taper of about ⅛-in. per ft. from the rear bridge wall to the front tap hole, and ⅜-in. per ft. from front tap hole to front end wall (burner end). A second template should be used crosswise of the furnace to give a fall of approximately 2-in. from the center of the furnace bottom to the tap holes on each side of the furnace. Sand bottoms, for best results, should be tamped or rammed in position. The reason that the bottom is so shaped is to permit of rapid drainage of the iron from the furnace without excessive oxidation throughout the pouring of the heat.

21. A new furnace bottom should be protected with ½-in. or greater thickness of boards, before the first charge is placed in the furnace. In some cases, it is preferable to prefire a bottom. With good furnace practice, sand used for this purpose should not exceed 20 lb. of sand per ton of iron melted.

22. When iron is found in a bottom at the end of a week's run

or longer, the entire bottom should be replaced. Patching of a sand bottom has never proven satisfactory or economical.

23. When melting tonnages in excess of 35 tons per heat, it has been found advisable to use brick bottoms. Brick for this purpose should be hard burned, and, in some cases, the use of a superduty brick has paid dividends. When using brick bottoms, a life of 3000 to 6000 tons of metal or more is possible before failure. Furnaces, to give a reasonable life with brick bottoms, should be more sturdily built than when using sand bottoms. Facility for air circulation under a brick bottom should be provided. Brick bottoms can be satisfactorily repaired by careful workmen.

24. *Side Walls:* Height of furnace wall at the lowest point of bottom is governed by the tonnage being melted in a particular furnace. On a furnace melting 18 to 25 ton heats, the height of the wall inside the furnace should be 30-in., less than 18 tons, 28-in., and 25 to 35 tons, 34-in. In some cases, when the scrap charged is bulky, it is necessary to increase the wall height. It is more desirable to do this than to have the furnace over-crowded and not have adequate combustion space.

25. Various types of side wall construction are used. In some cases, with small furnaces, a 9-in. side wall is used. In general practice, it is customary to use a 4½-in. safety wall and a 9-in. header course. The header course is all that is removed during a repair. Brick should be first quality and hard burned.

26. *Rear Bridge Wall:* The height of the bridge wall varies with the tonnage being melted, but in no case should it be more than 4-in. above the slag line in the furnace. The bridge wall should be inspected daily and kept at a uniform height by using sand on top of the brick. The brick in the bridge wall should, at all times, be protected with sand. The opening over the rear bridge wall should be about 1050 sq. in. It is necessary that the opening be kept uniform as it controls the back pressure in the furnace in conjunction with the stack. The back pressure in a furnace should be the same at all times. It is possible to rig up a draft gauge which would be of considerable value in holding a uniform draft condition in a furnace. For rapid melting, the writer prefers almost a balanced draft condition in the furnace.

27. *Stack or Stack With Underground Flue:* The stack, in conjunction with the opening over the rear bridge wall, controls the furnace pressures. Therefore, it is necessary that the stack and underground flue be kept reasonably clean at all times.

Fuel

28. The type of coal being used, whether long or short flame, requires a different technique in firing. When a technique is determined for firing a grade of coal, it should be followed at all times when using that coal. The condition of the coal, whether wet or dry, affects the procedure used and must be taken into consideration at all times. It has a considerable effect on carbon control in the metal.

29. The fineness of the pulverized coal should be kept reasonably uniform. This should be controlled by weekly fineness tests on each furnace pulverizer, and at no time should the fineness of the coal go below 60 per cent through the 200 mesh. Bag sampling is most accurate and should be used for fineness tests.

30. For uniformity in feeding which is irregular with coal containing over 3.0 per cent moisture, coal should be stored under cover for at least 75 per cent of winter requirements and 25 per cent of summer requirements. Covered storage for entire supply is desirable.

Melting Furnace Charge

31. The furnace charge, in per cent of different materials used, will depend upon individual plant conditions and is determined by such factors as carbon content of metal desired, amount of sprue produced, etc. In general the amount of pig iron required should not exceed 40 per cent or be less than 25 per cent, and the amount of malleable scrap should not exceed 15 per cent, the balance of the charge to be made up with sprue and hard iron scrap. If the carbon in the charge is not sufficiently low, steel can be used for further reduction.

32. In placing the charge in the furnace where heats are in excess of 12 tons, it is desirable to leave six 13½-in. bungs at the front of the furnace which places the charge far enough back from the burners to permit good combustion during the early firing period. Sprue should be placed on the furnace bottom and fairly well distributed over the length that the charge will require, having in mind that the charge toward the front, when completed, should be well up to the underside of the bungs. Malleable scrap should not be concentrated too much, but distributed over the sprue, and pig iron, in turn, distributed over this, the charge, when completed, tapering off toward the rear of the furnace. When railroad malleable or other coarse scrap is used, this may be charged first since it has a tendency to open the charge and permit

rapid heating. When steel is used, it should be placed on top of the charge nearest the burners or directly under the pig iron.

Firing Schedule

33. A firing schedule, depending upon the size of heats, should be adopted and adhered to. The firing schedule and all other information, including irregularities, should be noted on the furnace logs. In a proper schedule there are 4 steps or periods as follows: First, a small amount of coal and air, about ⅔ of maximum; second, a larger amount of coal and air, about ⅚ of maximum; third, maximum amounts of coal and air; and, fourth, the holding period after heats are tapped which, in some cases, will correspond to the first period and, in others, to the second period, depending upon the class of work and demand for temperature.

34. Where work is very light and extremely hot iron is necessary, the settings of the second period are desirable, but for medium or heavy work the first period settings are adequate. The length of the first and second periods will vary, depending upon the size of the heats and whether or not they are first or second heats. In general, the two periods for heats of 10 to 15 tons should be of 20 to 30 min. duration, and for heats 15 to 25 tons, 30 to 45 min. For second heats on hot furnaces, providing the lapse of time before starting fire does not exceed 2 hours, both periods may be shortened 10 to 15 min. After the full schedule is reached, there should be no occasion for changing either air or coal until after heats are tapped and running, when the setting should be changed to holding, as noted above.

35. Constant conformity of coal feed to indicated settings is vital. Ratchet feed should be checked daily by the melter to see that the pawls are pulling the number of teeth corresponding to coal feed settings. Likewise, when using the screw feed, it should be checked to be sure the dial setting is delivering the correct number of revolutions for that setting.

36. Another factor that is quite vital is that the coal hopper should, at all times, be kept filled with coal. If the hopper is not so kept, there will be quite a variation in coal feed due to variable pressure on the coal at the outlet to the feed belt or screw. The screw type feed is more uniform and, if possible, should be used.

37. Because of the more rapid melting and heating up of pulverized coal-fired furnaces, it is necessary to tap heats promptly and run them out quickly to avoid excessive oxidation of the metal

and use of an excessive amount of coal. This calls for a minimum interval after tests are taken and for promptness in tapping after heats are called. With maximum settings on a unit pulverizer, the amount of coal burned per hour is approximately 2,000 lb. A delay of 15 min. means 500 lb. of coal, which on a 20 ton heat is 25 lb. of coal per ton of iron melted.

Melting Furnace Oxidation

38. During the melting of the charge, carbon manganese and silicon are oxidized. With good melting practice oxidation is approximately as follows: Carbon, 0.40 per cent; silicon, 0.35 per cent; and manganese, 0.25 per cent. The other two elements with which we are concerned, namely, sulphur and phosphorus, will show a slight increase during melting. The sulphur will increase about 0.01 per cent due to a pick-up of sulphur from the fuel. The phosphorus will increase about 0.002 per cent due to concentration caused by oxidation of carbon, manganese, silicon and iron in the charge.

General Instructions for Making Up the Charge

39. Considering the oxidation during melting as outlined, it necessarily follows that adequate allowance be made in the composition of the charge to compensate for this loss. This is done by varying the percentages of pig iron, hard iron sprue, malleable scrap and, at times, steel, in the charge, depending, of course, on the desired analysis of the metal wanted.

Working of the Heat During Melting

40. In firing a furnace, a furnace man should never be permitted to make changes in the coal or air feed. Any changes that are made should be made by the melting foreman, and, once a schedule of operation has been developed, it should be religiously followed from day to day. Any changes in the composition of the resultant metal should be corrected by changes in the charge composition.

41. In firing a furnace, it is well to remember that the firing schedule should be so regulated that the furnace walls, furnace bottom and the charge be red hot throughout before melting starts, otherwise the first iron melted solidifies and has to be remelted, resulting in high oxidation and long melting time. The fire, at all times, should be slightly cloudy.

DISCUSSION

Presiding: D. P. FORBES, Gunite Foundries Corp., Rockford, Ill.

Co-Chairman: CARL F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

W. R. JAESCHKE[1] *(written discussion):* Mr. Durr's figures on fuel and coal ratios resemble those figures usually found in combustion handbooks dealing with combustion in pulverized coal-firing of boilers. In my experience, such high quantities of excess air have not been found in melting practice. In two specific instances, when engineers in customer plants made air measurements, the air used was never over 125 cubic feet per pound of coal fired. In a third instance, the air measurements indicated that the customer was using the theoretical requirement of 11.6 pounds of air per pound of carbon. The operation in this furnace was faulty, the metal was excessively oxidized, and the furnace refractories were badly fluxed by the oxidized metal. The coal-air ratio was enriched to overcome the faulty operation. In general, the writer finds that most operators fire with as low an air supply as possible and still be able to produce the necessary heat to melt properly. Mr. A. J. Grindle's experience corresponds to the writer's, and he agrees that excess air should be avoided in melting furnaces.

For best overall results from a melting furnace, it is not advisable to use coal ground too finely. Coal passing 90-95 per cent through 100 mesh screen is generally fine enough for firing a melting furnace. Firing with a coal that is finer than necessary causes localized overheating in the front end of the furnace. The usual practice is to start or light up a furnace with fine coal and then progressively decrease the fineness as the heat input is increased and furnace temperature increases. The coal fineness may advantageously be increased up to a point where coarse particles might fall onto the metal bath. It is the coal that will not pass 40 or 50 mesh screens that drops out of suspension. Coal fineness should also be varied according to the type of coal used. Lower volatile coals should be ground finer than the higher volatile coals to promote quick ignition. This flexibility in coal fineness control is possible only with certain types of unit pulverizer installations.

The burners on furnaces designed by the writer's company for batch melting are set at an angle of 25° from horizontal and at a definite level above the normal metal line. This setting is the result of early development work and furnaces with this standard setting are among the most efficient. For duplex melting furnaces and particularly single burner furnaces, the burner angle has advantageously been reduced to 10° and even less. A corresponding reduction was made in the height of the burner setting so as to maintain the proper point of impingement of the flame onto the surface of the metal bath.

Mr. Durr states a preference for burners that can be adjusted to any angle during the melting of the heat, but gives no reasons for this preference. On the other hand, it appears to me to be in conflict with his advice in paragraph 13 to standardize the melting procedure.

[1] Whiting Corp., Harvey, Ill.

MR. DURR *(written discussion):* The coal and air figures to which Mr. Jaeschke refers in Table 1 were used in the paper to indicate temperatures that could be obtained with pulverized coal and not what could be used in good melting practice. The paper, as far as paragraph 13, deals with characteristics of pulverized coal and temperatures that can be obtained and not with air furnace practice.

The writer does not agree with Mr. Jaeschke regarding coal fineness. If a furnace is correctly fired with fine coal, that is, with 80 per cent or more of the coal passing through the 200 mesh, it will be found that less coal will be necessary and more rapid melting will result.

There are so many variables in unit-system firing that it is difficult at any time to determine how much coal and air are being used.

The use of adjustable burners is advocated because, at various times in furnace operation, you find it desirable to deflect the flame to some part of the charge that is slow to melt. This condition develops from improper charging.

MEMBER: I would like to ask whether, with that low angle of the burner, any difficulty is experienced in blowing back the heavy slag?

MR. DURR: No, I have less difficulty in pushing back the slag. If it is too flat, there is not a real movement, or a fast movement of the slag.

M. E. MCKINNEY[2]: Mr. Durr states that an excess of air pays. On the other hand, it is the consensus of opinion that the air furnace should be run on a slightly reducing blast. These two opinions do not seem to agree. Therefore, I should like to have Mr. Durr's idea as to whether an excess of air should be used or an excess of combustibles to give a slightly reducing flame.

MR. DURR: That would depend largely upon the stage of the melting-down operation. For fast melting, I like to have a slightly oxidizing atmosphere. Later on, for holding, I like to have it the other way.

MR. MCKINNEY: Will Mr. Durr explain that in expressions of CO?

MR. DURR: In combustible, about 1 to 1½ per cent of combustible in the fuel is where I would like to run it after the heat is melting down, in order to hold the carbon reasonably constant.

MR. MCKINNEY: Have you analyzed the excess gases, to know that you are really getting excess when you do that?

MR. DURR: Yes, but it was quite a number of years ago, and I do not remember the exact figures.

MR. MCKINNEY: I would like to say that we have done quite a few analyses on exit gases of powdered-coal-fired furnaces, and I wonder if anyone else in the assembly has done the same, so that it will be possible to check and determine if the results we have been getting are normal?

We have found that the hottest and fastest melting down is with a CO of about 2 per cent, with an excess of somewhere between 3 and 4 per cent CO for holding metal.

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[2] International Harvester Co., Hamilton, Ontario, Canada.

CHAIRMAN FORBES: Does anyone have any comments? Aubrey Grindle, I should think that possibly you might have something to say.

AUBREY GRINDLE[3]: It is possible to arrive at different results in different ways. For instance, on this angle problem, we melted our first malleable iron in 1919 with a 30° angle, and we obtained fairly satisfactory results, but as time went by we discovered that the roof in the rear of the furnace was melting away with the burner angles at that degree. Firms which are duplexing have burners at an angle as low as 10° on their furnaces. It is possible that they can go a little lower. I think probably Mr. Durr's suggestions are good, for duplexing furnaces.

In regard to gas analysis: We ran tests at the Symington-Gould Corp. in Rochester, N. Y., where we had the various experts check us, and, because of high temperature, we were running over 20 per cent CO_2. We still do not know whether to accept the findings. However, I think that Mr. McKinney's idea of operating with about 2 per cent CO when melting down would be quite satisfactory. I do not like an oxidizing flame at any time on a melting furnace. Four or 5 per cent CO until the heat is melted down should prevent excessive oxidation, then 2 per cent would be all right until the iron is hot. At tapping time the CO should be again increased to 4 or 5 per cent.

I do not recall that we have ever analyzed the gases at the exit of the furnace. On the duplexing furnace, we run with an oxidizing flame while receiving iron from the cupola. Melting in the cupola produces high carbon, and it is necessary to reduce this by excess oxygen. There may be a little CO, depending upon the fineness of the coal. Fineness also has a lot to do with gas analysis and proper burner angle.

I would like to know if Mr. Durr has found a 10° angle satisfactory with coal from an impact pulverizer when it is about worn out?

MR. DURR: I have not.

MR. GRINDLE: I think his experience is based upon melting with the central system where there is fine coal, or uniform coal, at all times.

DR. H. A. SCHWARTZ[4]: Mr. Chairman, I wonder if Mr. Durr would like to say something about the fineness of coal.

MR. DURR: Personally, I like coal 85 per cent, or better, through the 200-mesh screen. As a general rule, you have to get that in a central system, a semi-central system, or something of that nature. When you get the other type of pulverization—unit type—then there are coarser particles of coal, and, with the low burner angle, you usually experience trouble with carbon pick-up.

CHAIRMAN FORBES: Do you care to comment upon operation with high volatile coal?

MR. DURR: Again I prefer low volatile coal. On a furnace with a bath probably 30 ft. in length, I like to see coal with a volatile somewhere not over 22 per cent. In some air furnaces melting 90 to 100 tons, there is possibly a reason for using higher volatile coal. I feel that the same thing applies when using recuperation or preheated secondary air.

I might add that in recuperation with secondary air (carborundum

[3] Whiting Corp., Harvey, Ill.
[4] National Malleable and Steel Castings Co., Cleveland, Ohio.

tube-type recuperator), the combination of secondary and primary air temperature around 300°, some 20 to 25 per cent can be saved. If you get much higher than that, you run into various other difficulties, particularly with the unit-type pulverizer, and in some cases with the central system where the screw feed is on a tank, at the end of the melting furnace.

CHARLES MORRISON[5]: In regard to oxidizing and reducing flames, when you refer to an oxidizing flame, are you referring to the actual analysis of the gas coming out of the furnace or the speed with which the air and the fuel mix? Or, when you speak of reducing flame, are you speaking of the actual discharging of carbon monoxide due to insufficient air, or delayed combustion?

MR. DURR: It is hard to say whether it is insufficient air or not, based upon gas analyses at the back of the bridge wall. That question is extremely difficult to answer. In some cases I have questioned the gas analysis results.

MR. MORRISON: I was referring to luminous and non-luminous flames.

MR. DURR: In melting down I do not want a white flame; I prefer a slightly hazy flame which gas analyses, over the bridge wall, show to have free oxygen. The fact is that the flame might not be actually oxidizing, but that is what gas analyses would show.

MR. GRINDLE: There is a difference in proper gas analyses during the heat. When you start an air furnace melting down cold, you begin with a very smoky flame if you do not want to melt and freeze on the bottom. Therefore, for the first 1 or 2 hr., we melt with a smoky flame, high in CO. Also, we may have some free oxygen because of the lower temperatures. We cannot get a combination of oxygen and carbon at low temperatures, but, after the charge is melting down and the furnace is hot, the oxygen and carbon will combine and produce a more efficient flame.

At the end of a duplexing heat—the last 2 hr.—no iron is received from the cupola. Oxidation must then be stopped because the analyses are correct when you shut down the cupola. At that time we not only reduce our air in proportion to the coal, but we also coarsen the coal to deposit some coarse particles upon the bath to maintain carbon at the desired point.

MR. MCKINNEY: I seem to get the impression that the fineness of pulverization is decidedly different between the central pulverizing system and a unit pulverizer. I would like to ask what the normal difference in fineness would be between the two systems.

MR. GRINDLE: In most of the central systems, coal is pulverized to an average of about 85 per cent through 200 mesh. There are a few people who like it a little coarser, and at Albion Malleable I believe they went up to 96 per cent through 200 mesh on a test, but the pulverizing cost was so high that the benefits derived were not worth the extra cost of power and repairs. They reduced the fineness after the test to about 85 per cent through 200 mesh.

[5] Saginaw Malleable Iron Div., Saginaw, Mich.

In the unit system, when a new impact pulverizer is started on an air furnace, the fineness equals or exceeds the average fineness from the central pulverizing plant. As the hammers wear, the fineness drops, even with the new type air separation pulverizers, because everybody tries to get as much life as possible out of the hammers and liners. Consequently, the tendency is to run the pulverizers until they wear down to a point where the carbon cannot be controlled, when it is necessary to shut down and install new hammers.

The question may arise, "Why the unit system, then, instead of the central system?" Those who have a central system will probably back me up on the statement that the original cost is considerably lower with the unit system, although the operating, repair and power costs are higher.

MR. MCKINNEY: What is considered the point where you should put in new hammers?

MR. GRINDLE: I personally would not like to pulverize lower than 60 per cent through 200 mesh. Possibly 70 per cent would be a good place to repair. If you can use iron with carbon up to 2.70 or 2.80 per cent, you will have no trouble with 60 per cent through 200 mesh. If you have to produce 2.20 per cent carbon iron, you would not dare run under 70 per cent through 200 mesh, and probably a minimum of 75 per cent would be necessary.

DR. SCHWARTZ: Mr. Chairman, may I interject a word about the gas analysis? We seem to be inclined to judge whether a gas is oxidizing because it contains so much carbon dioxide, or so much carbon monoxide, or so much oxygen. Each of those numbers by itself does not mean a thing—it depends upon the relation of carbon monoxide to carbon dioxide. At temperatures of 1100°C., a mixture of carbon monoxide and carbon dioxide, which contains something like 96 per cent of carbon monoxide, will still burn carbon with the remaining carbon dioxide, so in that sense it is oxidizing.

At the same temperature, equilibrium in that case is with solid, pure iron; an iron oxide would begin to form if you had something like 65 or 70 per cent carbon monoxide and the rest carbon dioxide. The gas of this composition is oxidizing toward iron, though not toward carbon.

Therefore, the subject is being over-simplified by talking of one gas at a time and by omitting from the question, oxidizing to what?

DAVID TAMOR[6]: I would like to ask Dr. Schwartz what means he would use to test the affluent gases in production. In other words, the coal screw is a volume medium, not a weight medium. In a central system, the amount of coal going through will depend upon weather conditions, so you are really feeding the coal by volume rather than weight.

DR. SCHWARTZ: I believe you have asked for an answer to a question which is not solved. Gas analysis is a difficult thing to do as a control performance, if you have to sample melting furnace gases. About 1915 I made an extended survey of hand-fired furnaces. Our own company

[6] American Chain Malleable Foundry, York, Pa.

was running seven plants at the time, and we went to a few other people as well.

Somehow the skilled furnace man, by looking at the flame, kept those analyses so nearly alike that the gas analyses data on well-operated furnaces were the same at all plants, and I think that the person who does it all the time has a good idea of what is occurring by looking at the flame. The ideal would be to have a continuously operating CO recorder, or something of that kind. We tried that, but most of the information we have has been gleaned over a limited period of time, when we transferred the experimentation to the shop and did what we could to sample gases.

The sampling is, of course, the difficult part, and the only way I know of doing it is with a water-cooled sampling tube, so that the gases are chilled instantly and you do not get reaction during cooling, with inlets at several places across the furnace. It is necessary to keep moving the tube up and down and sideways.

That is not a thing you could possibly do every day while you are operating. In some other connections, we were quite sure we had some defects in physical properties when our carbon monoxide went too high in relation to carbon dioxide. I believe all we did in that case was to make an occasional gas analysis until the furnace crews got used to it.

MR. MCKINNEY: It is probably a little too soon for me to say much about this, but we are operating a continuous analyzer on our furnace with a certain measure of success. The sampling is made before the back bridge wall. The apparatus is of the type used as a gas analyzer on an automobile. The tube is put in the exhaust pipe, and the gases have to be blown through the analyzer.

It will not work on a furnace unless there is a certain pressure, but that pressure does not have to be very high. We expected, when it was first installed, that we would get variations, due to striations in gas, but we were very agreeably surprised to see that the needle is very steady with the sampling at that point just below the bungs, in front of the back bridge wall, and through the side of the furnace with the furnace under pressure.

It responds quite quickly to any change in air or coal at the end of the furnace, and we have found that it is much more exact than any visual examination on the part of the fireman. While we have only been running it for 3 or 4 weeks, we feel that we are going to get something out of it, although I did not intend to speak about it now because it is only in the experimental stages, but it does work.

MEMBER: I would like to ask if this gentleman has an instrument to register the furnace pressure? If not, how does he tell, on observing the doors, whether there is infiltration through the doors?

MR. MCKINNEY: We run the furnace so the flame is coming out all the time and there is no inward suction. We are going to add to the installation a pressure indicator in hundredths of an in. However, at the present time the tubes in which the samples are taken have an elbow and a "T," and when the flame comes out through the tube we consider that we are running under pressure.

The Cupola-Air Furnace Duplex Process For Production of Malleable Cast Iron

By F. J. Wurscher*, Buffalo, N. Y.

Abstract

Among the various systems employing the principle of duplex melting of metals, the combination of the cupola and the air furnace (reverberatory furnace) occupies a distinct and prominent place. In the malleable cast iron industry, this method is finding increased adaptation because of its inherent economic features. Expounding the practices involved in the operation of this system, the writer draws on his experience in the operation of such units over a period of several years and under varying premises.

Advantages of Cupola-Air Furnace Combination

1. From its inception, the malleable cast iron foundry has used the air furnace as the medium for melting its metal. This furnace lends itself readily to conversion to the duplex method as only minor changes in its construction are necessary for meeting its altered function, that of a holding furnace in which superheating and refining is to be accomplished. In the change-over from cold stock melting to duplexing, deviations in the technique of operation do not present any difficulties to a well trained furnace crew. Thus, by converting to duplex melting, capital investment may be restricted to the expenditure for installation of the cupola and its auxiliary equipment, provided that the existing air furnace, its size and general condition, coordinates with planned production and warrants its continued use. In certain instances, where a change in plant layout became necessary to meet increased and continuous production, it has been found expedient to install a new air furnace and to take advantage of improved design.

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Note: This paper was presented at a Session of Malleable Foundry Melting Symposium at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

Table 1

EFFECT OF HEARTH SIZE ON CARBON CONTENT

Resulting Total Carbon, per cent	*Hearth Area in Tons of Iron*	*Avg. Metal Depth, in.*	*Min. Tapping Temperature, °F.*	*Possible Tapping Temp., °F.*
2.30	22	4-7/8	2850	2900
2.40	20	5-5/16	2830	2880
2.50	18	5-5/16	2810	2860
2.60	16	6-5/8	2790	2840
2.70	14	7-5/8	2770	2820
2.80	12	8-7/8	2750	2800

2. Continuity of operation of the two furnaces and their flexibility to production, within reasonable limits, constitute advantages of this furnace combination. Because of the type of secondary melting units employed in other duplex systems, melting proceeds in batch-type operation, requiring multiple secondary furnaces, thereby increasing capital investment. In addition to this consideration, fuel and maintainance cost per ton of metal melted are generally lower for the cupola-air furnace method than any other, a salient factor in its favor.

PLANNING FOR PRODUCTION

3. When planning for production by the duplex process it becomes essential to take cognizance of the major premises involving production policies, because of their profound influence upon the selection of the proper equipment to assure a uniformly standard product. As such factors may be named:

(1) *Type or grade of malleable iron to be produced.*

a. Physical properties of the metal.
b. Chemical composition of the base metal.
c. Annealing cycle to be employed.
d. Annealing equipment.

(2) *Type of castings to be manufactured.*

a. Ultimate use of castings.
b. Permissible cross section range of castings.
c. Range of size and weight of castings.

(3) *Production range differential.*

a. Anticipated maximum and minimum production range.

EFFECT OF HEARTH SIZE ON CARBON CONTENT OF FINAL METAL

4. Table 1 illustrates the effect of hearth size of the air furnace upon the carbon content of the final metal. It is assumed that the metal from the cupola has a carbon content of 2.90 per cent and that it is held in the furnace for 2 hours.

CUPOLA OPERATION

5. Success or failure to produce a constantly uniform standard base metal rests with the operation of the primary melting unit, the cupola. Hence, it is imperative that this furnace receive the greatest attention in every detail. Voluminous literature dealing with the many phases in the operation and other details of this furnace have been published in the past. Continued research seeking information for further improvements in its use is being carried on. This paper attempts only citation of the major factors influencing controlled operation.

Raw Materials

6. Misconception of the importance of properly selected raw materials that can safely be used in the malleable iron producing cupola has often met with grievous results. It is, therefore, deemed advisable to refer to some of the basic considerations of this phase of cupola operation, without covering the subject in full.

7. Briefly touching upon the requirements for a suitable coke, it may generally be stated that it must possess a high crushing strength in the state of incandescence in order to support the metal charges. Coke size and its density will, to some extent, affect the burning rate and the carbon-sulphur pick-up by the molten metal. Chemical composition as to volatile matter, fixed carbon and ash content will furnish information relative to its ignition temperature, combustion requirement and slag production. Changes in the blending of coals used in the manufacture of the coke and deviations in the coking time or temperature have a decided effect on the performance of the coke in the cupola. The foundry of the writer's association uses for its 48-in. cupola a 3x5-in. coke size with satisfactory results. This coke is made by using a special blend of coals and gives a very low carbon absorption. Its main characteristics are a dense cellular structure and a

slow burning rate. Slow burning cokes tend to low carbon absorption; metal melted with that type of coke will show a lesser tendency to precipitation of primary graphite than a metal of like chemical composition melted with a fast burning coke.

8. A high grade limestone is most generally used as a flux. Dolomite and fluorspar are sometimes used in special applications. Purite, a fused soda-ash, finds use as an aid to fluid slag production and as a desulphurizer. The percentage of available bases in a flux determines its effectiveness. In the case of dolomite, it may be recalled that magnesium oxide is 1.4 times as reactive as calcium oxide.

9. Selection of pig iron must, of necessity, follow along metallurgical considerations. Malleable, foundry and silvery pig irons, either singly or in combination, form the virgin metal portion of the metal charge in varying percentages. Investigations have revealed that innate metallurgical characteristics of the pig iron, traceable to the ore used and blast furnace practice involved, may have decided bearing on the physical properties of the resultant malleable cast iron.

10. White iron and annealed iron scrap used in the metal charge originate within the individual foundry and are of known composition. They generally constitute the bulk of the charge, amounting from 40 to 55 per cent of the total weight. If foreign scrap is to be a part of the charge, careful chemical examination must precede its use. Cleaning of the white iron scrap of adhering sand by mechanical means is occasionally practiced, the point in view being that, in fluxing off the silicious compounds, heat is diverted from the combustion of the coke to liquification of that slag. Hence, an increase in coke consumption is the result. It has been the writer's experience that a light sandy scrap is not objectionable because of its aid to production of a large enough volume of slag which, in turn, provides for a better cleansing of the molten metal.

11. The steel scrap is the raw material of the charge most difficult to control, more so today than in the past, but even more so in the future, due to the ever increased use of alloys in steel manuture for war time purposes. It is essential that the steel have a low carbon content and be free of alloys, specifically those which retard graphitization. While small amounts of such alloys which sponsor graphitization are not detrimental, their presence must be compensated for by an adjustment in the chemical composition of the normal base metal. Because of the relatively large percentage

of steel scrap in the metal charge, from 25 to 40 per cent, the overall dimension of the scrap pieces is an important factor in the effect upon melting conditions in the cupola. The permissible length of any steel scrap piece should be less than half the diameter of the melting zone and its weight held to a maximum of 50 lb. The shape of the scrap shall not tend to intertwining which is generally the cause for charges to hang up in the cupola.

Air Supply

12. The air supply for the combustion of the coke is delivered to the wind belt of the cupola by either a positive displacement or a fan-type blower. An adequately sized blast pipe connects the blower to the wind belt. Control devices for measuring the amount of air required are frequently a part of the auxiliary equipment. These devices automatically measure and maintain the chosen air amount, they operate either on volume or air weight measure and their value to performance of the cupola is indispensable. Realization of the effect of the moisture in the air upon coke consumption and the metal itself has led to installations designed to control it. The results obtained fully justified the investment.

13. Utilization of the cupola's waste gases for preheating of the air also has found application in the malleable iron foundry. Savings in coke consumption have been reported through the use of such equipment. While air control equipment has materially improved cupola performance, it is regrettable that no such equipment has been designed for use on the air furnace which still depends on the operator's experience and eyesight for maintenance of the proper flame and atmosphere in the furnace.

Charging

14. In consequence of the features involved in duplex melting, hand charging had to be replaced by mechanical charging devices. The bottom drop bucket and elevator hoist charging or the various designed skip hoist chargers are but two of many mechanical charging arrangements. The writer's experience with the bottom drop charging equipment which allows for level charging of the metal in the cupola makes him partial to that method.

Design and Construction of Cupola

15. The design and construction of the cupola in the duplex system with the air furnace follows conventional conceptions. Straight or boshed lined cupolas are in use which may be of the

back or front slagging arrangement. Preference for the front slagging cupola is based on the consideration that on account of the greatly reduced well or hearth space only a small amount of liquid metal can collect which lessens the chances for additional carbon absorption by the molten iron by contact with the coke. To obtain a normal operation the size of the cold stock zone of the cupola should be large enough to accommodate a sufficient number of standard size metal charges, preferably the equivalent in tons to the standard hourly production rating of the cupola. The height of the stack above the charging door should be greater than that of the air furnace stack to avoid down draft conditions arising which are adverse to rapid dispersion of the cupola smoke.

16. The subject of tuyere construction, their number, size, shape and location, is one of a controversial nature. Many special tuyeres have been designed and tuyere arrangements developed in answer to a specific problem. However, the scope of this paper does not permit discussion of their merits. From personal experience, the writer prefers the ring or continuous type tuyere which has given consistently good results provided the tuyere ratio and height was correct for the respective cupola. The use of upper tuyeres in cupolas for duplexing is generally omitted because of the necessity of maintaining a considerably higher coke bed which, in turn, favors greater carbon absorption by the molten metal. Tuyeres have the function of providing the coke with sufficient air of such velocity at the point of entrance that it will reach to the center of the coke bed. Rate of combustion, temperature of the metal and erosion of the refractory lining are influenced by the functioning of the tuyeres. Checking the height and severity of erosion of the melting zone provides a criterion of the day's cupola operation.

17. In a duplex unit operated for the production of A.S.T.M. Specification 47-33, Grade 35018 malleable cast iron, the cupola employed is lined straight to 48-in. For the height of two rows of cupola blocks directly above the upper tuyere plate, the diameter is reduced to 44-in. to provide a 2-in. ledge on each side for the purpose of deflecting metal and slag drops from being carried into the tuyeres. Below the charging door, for a distance of about 5 ft., cast iron blocks are used in the lining to lessen the refractory consumption in that region due to the abrasive and impact action of the metal charge. The remainder of the cupola lining is made with a high grade cupola block.

18. Six tuyeres are provided which have a combined opening area of 25 per cent of the cross section area of the melting zone.

Eight segmentary upper and lower tuyere plates, held apart by 4-in. high, tapered cast iron lugs, form the continuous tuyere arrangement. A 1¾-in. diameter tap hole rammed up daily and using a highly refractory and slag resisting ganister mixture takes care adequately of the metal and slag volume produced under a melting rate up to 12 tons per hour. The cupola spout enters the air furnace at a distance of 2 ft. from the bridge wall and is so constructed that a dam arrangement separates the slag from the molten iron. The head pressure of the metal in the dam pit determines the volume flow of iron and slag. If it becomes greater than the existing pressure in the cupola well, the slag will accumulate within the cupola and eventually run into the tuyeres. On the cupola in question the dam pit measures 35-in. in length, 7-in. in width and 7½-in. in effective height, leaving a passage opening for the molten iron under the dam brick of 7x1¾-in. The well space of the cupola measures 48-in. in diameter by 18-in. high. An 8-in. sand bottom reduces the effective well volume to about 10 cu. ft., of which approximately only 40 per cent is available for collection of molten metal.

Design, Construction and Operation of Air Furnace

19. The air furnace of the duplex unit being described is of the improved design, having the air-cooled bottom feature. An L-shaped flue connects the furnace to the stack. The over-all dimensions of an air furnace are governed by the area required in square feet to give the proper carbon reduction. The usual ratio of width to the length of the furnace is about 4½ to 1. The dimensions of the air furnace in operation are 31 ft. in length by 7 ft. 6-in. in width. Two courses of fire brick, 18-in. high, form the foundation bottom upon which the final bottom is laid. The fire brick used in the foundation bottom are of the high alumina type (40 to 50 per cent). This bottom tapers ⅛-in. per ft. from the bridge wall toward the tap hole line and more sharply toward the burner wall. The brick bottom is tied into the side walls without a provision of an expansion joint. The average bottom life is about 2000 tons of metal melted. A first quality fire brick is used in building the 13-in. side walls. Slag erosion at the metal line compels replacement of the inside course of the side wall weekly. Three 1-in. diameter tap holes provide for draining of the furnace. Two of them are located at the same level with a center-line of 16-in., and the third is placed 2½-in. below and takes care of the final drainage of the hearth. Metal depth at the tapping line measures

6-in. which in conjunction with a hearth surface area of about 232 sq. ft. gives an anticipated max. carbon reduction of 0.4 per cent.

20. The bridge wall opening governs the amount of coal burnt per hour and averages 2.50 lb. of coal per sq. in. of opening. The bridge wall opening of this furnace measures 17-in. high by 62-in. wide which allows for an average coal consumption of 240 lb. per ton of iron for a 10 to 12 ton hourly production rate. The bridge wall opening should, of course, be controlled in proportion with the stack draft to create a slight pressure at the skim door. The stack height shall preferably be 50 ft. with a 1.4-in. inside area per lb. of coal burned per hour.

21. Two water-cooled burners fire this furnace. Their inside dimension at the mouth measures 7½-in. x 13¾-in. It has been found by experience that 7½ to 10 degrees is the best burner angle for duplex furnaces. Burners should be located close enough to the metal line to cause the flame to skim across the top of the metal, thereby eliminating the creation of a hot spot on the furnace bottom as in the case of a steeper angle where the flame is directed down on a definite spot. Longer bung brick life results from a lesser burner angle.

22. A straight, tapered bung line differentiates the duplex air furnace from the camel-back line of the old, cold melt furnace. Measuring from the furnace bottom to the crown of the bung, the roof tapers from 38-in. near the burner wall to 28-in. at the bridge wall. A bung radius of 10 ft. to the underside of the bung brick has been found to be best.

23. The furnace is fired by means of pulverized coal produced by an individual pulverizing unit. West Virginia slack coal of a 22 to 25 per cent volatile and low ash content is used. The degree of fineness of pulverization is controllable by an adjustment provision on the pulverizer. Checking the fineness of the pulverized coal will indicate the necessity for changing of the beaters and liners which in this case are made of surface flame hardened "Z" metal, lasting approximately 30 to 40 operating days. Equipping the air furnace with a unit pulverizer has the advantage over the centralized pulverizing system as it permits the operator to adjust the degree of pulverization in order to maintain carbon and silicon composition of the metal in the last stage of the daily heat.

PROCEDURE

Cupola Charge

24. To obtain a base metal which would produce the 35018

A.S.T.M. Specification under the annealing cycle employed, the foundry of the writer's association standardized its cupola operation to a 1500 lb. metal charge consisting of:

	Per Cent
Malleable or foundry pig iron	10
Silvery pig iron	5
Domestic and foreign malleable scrap	4
Steel scrap	30
White iron scrap	51

Deficiency of the manganese content in the charge is compensated for by the addition of the necessary amount of ferromanganese or spiegeleisen. Adjustments in the amounts of these proportions are made daily depending on the availability of materials and chemical composition of the metal at the air furnace spout. The final white iron analysis aimed for falls within the following tolerance:

	Per Cent
Total carbon	2.35 to 2.40
Manganese	0.45 to 0.50
Phosphorus	0.12 to 0.15
Silicon	1.15 to 1.20
Sulphur	0.14 to 0.16

While above tolerance limits represent acceptable values, the actual performance of this unit produces very small variation in the chemical composition of the iron during a 9 hour melting period. No attempt is being made to desulphurize the metal from the cupola. The sulphur is adequately dealt with by maintaining a manganese-sulphur ratio of 3 to 1.

Air Volume

25. Based upon a coke ratio of 10 to 1, a precalculated air volume is supplied to the cupola by means of a fan-type blower, automatically controlled by an air weight device to conform with the day's hourly production rate of the foundry. Only minor adjustments in the melting speed of the unit are permitted to assure maintenance of a constant volume of iron in the air furnace, essential to a consistent metal composition. Particular attention is given the preparation of the cupola for the ensuing heat, because of its profound influence on the primary metal to be produced.

Lining of Melting Zone

26. The lining of the melting zone is carefully restored to the original dimension after each day's performance. Clean molding sand of a permeability of about 120 and a moisture content of 4 per cent is used in the making of the sand bottom. Small size, easily burning kindling wood is placed in the well and ignited through the tuyeres by means of an oil torch. One third of the necessary coke bed is added and allowed to burn to a bright red, using the cupola draft only. Before placing of the second portion, all kindling wood must be completely burned. This second portion of the coke bed is permitted to burn sufficiently so as to show an even red over the entire area. The last coke addition is placed so as to make the height of the coke bed 44-in., ascertained by means of a measuring rod.

Charging

27. Charging then commences immediately. The cupola holds 7 standard 1500 lb. metal charges. The cupola is blown in with the necessary air volume corresponding to a melting rate of 10 tons per hour and permitted to operate at that speed until the air furnace is filled. One and one-half hours are required to melt the 15 tons in the air furnace hearth at the time pouring begins in the foundry. Preceding the pouring, an interval of 20 min. is needed to bring the transport and hand pouring ladles to the desired temperature, using the air furnace metal for that purpose and pouring it back into the furnace. Slag from the cupola begins to flow off the spout within 40 min. from the time the blast is turned on. It is collected in tapered containers suspended from a jib-hoist. The containers are replaced as needed and emptied at the conclusion of the day's heat. The air furnace is skimmed free of slag about ½ to ¾ hours before tapping.

28. The air furnace is gradually brought to temperature, starting 2½ hours in advance of the melting time for the cupola, and, by adjustment of the flame during the period of filling of the furnace with cupola metal, the bath is being oxidized to the desired carbon content. During the day's operation the experience and adjustment of the flame by the melter governs its control. Periodic examination of the cupola and air furnace slag furnishes translatory information pertaining to the proceedings within the two furnaces.

29. Frequent observation of the behavior of the molten metal in the hearth of the air furnace furnishes the necessary clues pertain-

ing to existing conditions which affect the degree of oxidization of the carbon in the melt. Alloys and petrol coke are added to the molten bath occasionally in small amounts to maintain as close a chemical composition as it is possible to obtain. Should unforeseen interruptions in production occur which involve delay in distribution of the metal through the foundry, the cupola is shut down rather than blown at a reduced rate of production. In addition, the air furnace is made ready to allow for an extended holding period without endangering the metal composition. Such precautions involve the creation of a protective slag cover over the entire surface, reducing the flame and an adjustment in pulverization fineness.

Uniform Metal Composition

30. To assist the melter in his task of maintaining a uniform metal composition, a preliminary test piece is poured one hour before tapping time and then each hour following. These test pieces measure 6-in. in length and are ¾-in. square, cast in a sand mold and gated to assure a sound casting free of shrinkage. They are sent to the chemical laboratory where drillings are taken following a standard procedure and analyzed for total carbon, silicon, manganese and sulphur. A phosphorus determination is made daily on one of the test pieces. It requires one hour for the completion of the analysis, and the results are phoned to the cupola as soon as they are obtained. Due to the difficulty of collecting a representative sample of the metal from the cupola, no attempts are made to ascertain the chemical composition of the metal at the cupola spout. In addition to the samples for chemical analysis, a test sprue is taken hourly or more frequently, as the case necessitates, and, from its fracture, evaluation of the metal composition is drawn. Corresponding to the control tests for the melter, other test pieces are poured each hour to serve as a control measure of the annealing cycle of each annealing oven. They are placed in the respective pots and broken after completion of the anneal by the inspector prior to the acceptance of the castings contained in the pot. A set of standard A.S.T.M. test bars and test wedges are also poured each hour, thus completing the established series of control tests. All pertinent data of each day's operation of the furnaces are compiled on a melt sheet and are used by the metallurgical department in correlating results of physical properties obtained on the test bars and test wedges.

31. Frequent microscopic examination of test pieces and cast-

ings is made and every abnormal structure or result encountered is tested microscopically in an attempt to seek the reason accountable for it. Revelations by the microscope often point to faulty conditions existing elsewhere in the processes of manufacture rather than in the metal itself.

Annealing

32. With the metal composition cited and the furnace operation described, a white iron is produced which responds readily to an annealing cycle of 72 hours using the car-type annealing oven of about 12 to 15 ton casting capacity, fired by means of pulverized coal produced by individual unit pulverizers.

CONCLUSION

33. By better application of metallurgical knowledge in the operation of the melting furnaces, a more reliable and uniform quality product has resulted. Mechanical control equipment has lessened the range of error in the melting department, but, in order to extend the effects of such improvements over the foundry as a unit, much constructive work needs yet to be done in the control of other materials in the production of castings, such as molding sand and resultant mold properties. The eminent effects of mold properties upon the rate of solidification of the molten metal which, in turn, has a strong bearing on the final physical properties of the casting has not been sufficiently recognized by the average foundry so as to pursue adequate control efforts for the preparations of the molding sand with respect to the resultant mold properties. Because of this, even with the soundest metal, defective castings are still an appreciable factor in the production cost of many foundries.

DISCUSSION

Presiding: DR. H. A. SCHWARTZ, National Malleable and Steel Castings Co., Cleveland, Ohio.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

H. M. LANE[1]: I would like to know the temperature of the metal flowing from the cupola into the air furnace.

MR. WURSCHER: The metal from the cupola runs around 2830°F. Metal out of the air furnace at the spout, measured by an optical pyrometer, runs about 2930°F.

MILTON TILLEY[2]: What is the carbon content?

MR. WURSCHER: We do not ascertain carbon content of the metal at the cupola spout for the simple reason that we feel we cannot obtain a representative sample from the spout. Rather than allow results which are dubious, we refrain from taking it. However, it is assumed that we are getting in the neighborhood of between 2.65 and 2.70 per cent.

MR. TILLEY: Have you experienced any change in the carbon pick-up with the increase of diameter of the cupola, as the diameter increases during the day?

MR. WURSCHER: No, we have not found any appreciable difference in the carbon content for a 9-hr. heat. Granting the range of error that the chemical analysis and rapid determination of carbon involves, we are averaging about 7 points from start to finish.

MR. TILLEY: We notice a pick-up of about 5 points.

MR. LANE: About what is the coke ratio in the cupola?

MR. WURSCHER: 1 to 10.

DAVID TAMOR[3]: We run cupola carbons every hour and I might answer the question asked a little while ago. For about the first 4 or 5 hr. of a 9 or 10-hr. cupola heat, we will run between 2.60 and 2.70 per cent carbon but during the last few hours, the bed goes down quite a bit with the carbons dropping possibly as low as 2.40 or 2.50 per cent. During most of the operation an effort is made to maintain the bed, while towards the end it is sometimes a question if the benefit of extra coke additions can be appreciated.

Sometimes, when the bed is low enough, the slag comes out of the tuyeres, and it is questionable whether the day can be saved. It is our experience, that during the last few hours, cupola carbons will drop anywhere from 10 to 25 points, or even as much as 30 points. We have taken samples about ½ hr. before dropping bottom to check this, using a ground up shot sample.

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[1] Grosse Isle, Mich.
[2] National Malleable and Steel Castings Co., Cleveland, Ohio.
[3] American Chain Malleable Foundry, York, Pa.

MR. WURSCHER: If this is taken as an item solely by itself, by reducing the total charge from 2500 lb. to 1500 lb., we have more consistent results.

J. M. URBAN[4]: What size cupola coke do you use?

MR. WURSCHER: 3-in. by 5-in.

MR. URBAN: Did you ever use 4-in. by 6-in., and what results did you have?

MR. WURSCHER: We have not used it consistently. When we get a larger coke, we usually experience a greater pick-up in carbon.

JOHN N. JOHNSON[5]: Have you experimented with alterations in the composition of your cupola charge, variations in the amount of pig iron used and the amount of steel used?

MR. WURSCHER: Yes, we have changed the composition of our metal charge to counteract certain deficiencies which have occurred.

MR. JOHNSON: My particular interest is in the production of primary graphite in the casting.

MR. WURSCHER: The question of primary graphite has been raised a number of times in this convention. I do not know whether I am just lucky, but we are making jobs, the greatest cross-section that I can recall being 2-in., and I have yet to see a piece of casting that has shown primary graphite detectable in the hard iron state, or following the anneal, under the microscope. Whether that might be attributable to the high sulphur manganese ratio is a point open to controversy.

W. R. JAESCHKE[6]: In relation to that primary graphite, do you do much "doping" in the furnace?

MR. WURSCHER: Hardly any—it is not the general practice. We like to get down into the furnace, metal from the cupola, in such a manner that it comes out the way we want it. Of course, there are occasional hold-ups in the foundry; I spoke of emergency cases. If we are compelled to hold for some reason, we naturally have to make additions to the furnace. First, we usually try to counteract it with the flame, but rapid changes in the composition cannot be expected to be controlled by manipulation of the flame, so we resort to some silicon or manganese additions in that case.

GOTTFRID OLSON[7]: The speaker says that he gets an iron or coke ratio of 10 to 1. How much air are you using, in lb. or cubic ft., per lb. of coke used between charges?

MR. WURSCHER: I have not got the information at hand right now, but it is an easy calculation. We use 260 lb. of air per min. on a 10-ton per hr. production.

M. E. MCKINNEY[8]: Do you have a definite blast regulation in your lb. per min., and what peak windbox pressures are necessary to push this amount of air through the cupola?

MR. WURSCHER: The peak windbox pressure is 10 oz.

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[4] Fanner Manufacturing Co., Cleveland, Ohio.
[5] Union Malleable Iron Co., East Moline, Ill.
[6] Whiting Corp., Harvey, Ill.
[7] National Foundries Association, Chicago, Ill.
[8] International Harvester Co., Hamilton, Ontario, Canada.

MR. TAMOR: We have a problem that apparently you do not have. Most duplexers have a little trouble with carbon, manganese and silicon reductions after the cupola bottom is dropped. Let us assume that the bottom is dropped about 1 p. m., and at 4 p. m. you are through pouring at the air furnace. This gives a stand-by period of 3 hr. Let us also assume that, previous to that stand-by period, air furnace carbons ran 2.30 to 2.40 per cent. Now the cupola bottom is dropped and the sensible thing, of course, is to decrease air or increase coal and still hold the bath at the proper temperature. If you were to take a sample at 3 p. m., assuming that you were going out at 4 p. m., how much of a carbon, manganese and silicon reduction would you expect? Also, what do you do during the last hour of operations to counteract oxidation?

MR. WURSCHER: Your first question indicates an emergency. If it takes 3 hr. to pour 8 tons, you should know it on the same day before you drop the bottom.

If we encounter a condition of that sort, and we know it is going to take us twice the time that is ordinarily required to empty the furnace, we resort to making a change in the last few charges before they enter the cupola; i. e., by leaving out the steel altogether.

MR. TAMOR: You are implying that 3 hr. is too long a time for a stand-by period. Are you suggesting an adjustment of the melting rate to eliminate the 3-hr. stand-by period?

MR. WURSCHER: Is the 3-hr. emptying period of your furnace standard procedure?

MR. TAMOR: I just assumed 3 hr. To be exact, our stand-by period would be nearer 2 hr., but in those 2 hr. we have to recarburize, and sometimes have to add silicon and manganese.

MR. WURSCHER: In a case of that type, if it is possible to recognize such extended pouring time, we provide for it by eliminating the steel from a number of charges which go into the cupola last, thereby hoping to maintain the carbon. In this case, we resort to frequent sprue tests in order to ascertain how much we lose. At the same time, we try to work our slag, keeping the bath as heavily slag-covered as possible, within the bounds of safety.

Also, we resort to the flame adjustment, and, if it happens to be necessary, we utilize coarsely ground coal. If you have your slag on the furnace, and pour coarsely ground coal into it, you are holding the silicon as well as the carbon, because you get the reaction between the carbon and the silicious products of your slag.

MR. TAMOR: Our experience has been that a slag is sometimes more oxidizing than air. When we have a heavy slag we oxidize more elements than if we have a nice clean bath.

MR. WURSCHER: That is not my experience. We usually pick up quite a bit of silicon if we have to do that.

MR. TAMOR: If we assume that no additions are made, and if we have 2.25 per cent carbon at 1:30 p. m. with a clean bath, then the 2:30 p. m. sample might show 2.15 per cent carbon. When we get carbon reduction, our silicon may go up 10 points while our manganese is static.

This occurs at temperatures running approximately the same as yours.

I have never tried to operate with a heavy slag. I have tried a lime slag without any oxidation, but I certainly steer away from heavy oxidizing slags.

MR. WURSCHER: Periodically, we run analyses from the time the cupola is finished to the last ladle. I would say that there is approximately a 10 to 25-point drop in carbon in the last ton of iron. When we were running around 2.40 per cent carbon, the last drop out of the iron was still 2.32 per cent.

MR. TAMOR: What was your silicon with your 2.32 per cent carbon?

MR. WURSCHER: The silicon was a little higher; it was running about 1.20 or 1.25 per cent. You pick up 5 or 7 points of silicon readily.

MR. TAMOR: What I was really trying to determine is whether the oxidation is in the operation of the flame or not. I was just wondering whether anything could be done to overcome this oxidation towards the close of the heat.

MR. WURSCHER: The first thing we do, naturally, is to drop the flame as low as possible. Then, if it is an excessive length of time, we resort to changing the last charges that go in. If that should prove inadequate we employ slag manipulation, and, in the last resort, we make additions because I have found that any metal condition—any alloy addition—that is made in the last stage of the heat always results in disaster after the metal comes out of the annealing room.

MR. OLSON: I am not quite satisfied with the figures that Mr. Wurscher has given on the air. He used about 6 lb. of air per lb. of coke used, or approximately 75 or 80 cubic ft. of air per lb. of coke burned. I have not heard of such figures before, and I want to be sure that you are right when you say 260 lb. per min. That amounts to 15,600 lb. per hr. If we melt 12 tons per hr., that means 24,000 lb. of iron, or 2400 lb. of coke. Now if we use 2400 lb. of coke and put in 15,600 lb. of air, that leaves about 6 lb. of air per lb. of coke. I cannot melt iron that way—I wonder if anybody else can?

MR. TILLEY: I can give you our experience which checks very closely with Mr. Wurscher's. We melt 2½ to 3 times as fast as he does. We use 10 to 1 ratio and we use about 3 times as much air as he uses, 750 lb. of air per min.

MR. MCKINNEY: I might clarify a few points on that. There are two things that have not been taken into consideration. In the first place, 260 lb. of air is not lb. of air used for melting; they include the loss by leakage, and the coke figure includes the loss by carbon pick-up in the cupola. Consequently, both of those should be taken into consideration before a combustion balance sheet could be run.

Melting Malleable Iron with Oil in the Air Furnace

By A. Van Lantschoot*, Fairfield, Iowa

Abstract

The oil-fired furnace is most efficiently operated with the least amount of air necessary for complete combustion. The top blast, or secondary air, is considered necessary in oil melting. Low air pressure, as well as a low stack, is desirable. Only one burner of simple design is used and the oil is atomized by steam pressure. A flow meter is considered indispensable for uniform results. Uniformity of operation and the ability to produce the desired composition as soon as the metal has attained the proper pouring temperature are outstanding advantages. Refractories are important, and simple service records covering the life of the bungs are kept because, in addition to valuable information given, they stimulate the melter's interest in decreased refractory consumption. The effect of silicon and carbon on tensile properties is shown and the most desirable silicon-carbon ranges are indicated. The effect of low carbon on shrinks is also covered.

1. Very few of the numerous melting furnaces in operation at the present time are oil fired. While this statement could easily convey the impression that the use of fuel oil in air furnace practice should be frowned upon, the fact remains that efficient application of this excellent fuel yields very satisfactory results.

2. In determining the superiority of any of the existing melting methods, the important factors of plant capacity and geographical location with reference to the various fuel and metal sources of supply are generally taken into consideration. The relative costs of oil and coal and of malleable scrap and pig iron involve items of economy that should be fully recognized. However, a

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geographical plant location may easily reduce the difference in fuel and metal costs to such an extent that the advantages of lower fuel and scrap costs become of no greater importance than the advantages of rapid melting, excellent melting control, consistently dependable and uniform metal, economical furnace operation, low maintenance and fuel handling costs, efficient fuel distribution and a simplified storage problem.

3. In considering the advantage of a fuel from the cost angle, the actual difference in fuel cost per ton of melt should be taken into consideration rather than the difference in cost, calculated from the calorific angle. The B.T.U. cost of fuel oil, for instance, may run 50 per cent higher than the heat unit cost of coal. However, the thermal efficiency of fuel oil being greater, the actual heat unit requirements in oil melting may easily run 20 per cent lower than in present coal practice. A comparison of the pounds of coal and the gallons of oil normally required per ton of melt translated into total B.T.U. requirements will prove the foregoing statement. After all, a gain in efficiency of only one per cent, effected through better utilization, actually amounts to a 10 per cent fuel reduction. Unquestionably, such gain is readily accomplished because fuel oil lends itself to greater efficiency in utilization. Furthermore, better results are regularly obtained with a reduced rather than an increased amount of fuel.

CHARACTERISTICS OF FUEL OIL

4. Fuel oil, like gasoline, kerosene and lubricating oils, is a petroleum product, separated from the original crude oils by means of cracking stills. These various petroleum products separate according to their definite boiling range, modified by the method of operating the cracking plant. Petroleum yields an average of 35 per cent fuel oil, which is classified in 6 grades. The 3 heavier grades, intended for commercial purposes and industrial use, are most suitable for melting, although these three grades vary greatly in physical characteristics, of which only the gravity, viscosity and pour point are of importance.

Gravity

5. The gravity of fuel oil is a measure of weight rather than an indicator of quality and burning characteristics. Thus, an oil with an A.P.I.* gravity of 12 weighs approximately 10 per cent

* American Petroleum Institute.

heavier than a 26 A.P.I. gravity fuel. The lighter oil, on the other hand, will yield 4 per cent more B.T.U's per lb. Any fuel oil within the 10-28 gravity range is satisfactory for the type of burner used for melting.

Viscosity

6. The viscosity of oil is a measure of its resistance to flow at a specified temperature running close to actual use conditions. An oil with a high viscosity will not atomize as freely as the more fluid types, but the objection is not at all serious with the simple external mixing type burners used for melting and annealing.

Pour Point

7. The pour point refers to the lowest temperature at which an oil will flow and remain in a liquid state. This is an important item because an oil that will not flow at a certain temperature cannot be pumped without heating. A large vertical storage tank of 300,000 gal. capacity virtually solves the pour point problem in this plant, because it eliminates the necessity for heating the oil before unloading. The bulk of the fuel oil used is of the heavier 10-16 A.P.I. grade and stored to capacity during the mild seasons. For additional requirements during the winter months, a lighter grade fuel oil is purchased, usually the No. 4 grade with a 22-26 gravity and a zero pour point.

FURNACE CONSTRUCTION

8. The construction of an oil-fired furnace should be as simple as possible in order to obtain a correct furnace atmosphere, proper velocity of the gases and the best possible heat absorption by the scattered charge. High air and atomizing pressures, as well as excessive draft, should be avoided for best results.

9. A fifteen ton melting furnace is shown in Fig. 1. This furnace was originally constructed for hand firing and, in order to give the combustion chamber the desired length, a short extension was built on brackets fastened to the end plate of the fire box. In determining the size of the combustion chamber a number of items must be given consideration. Its length is dependent upon the type of burner used, as well as the pressure of the atomizing agent and the blast. A length of approximately 9 ft. gives the best results in connection with the external mixing burner used. The width and height are proportionate with the size of the furnace. The mouth of the combustion chamber is 18-in. narrower than

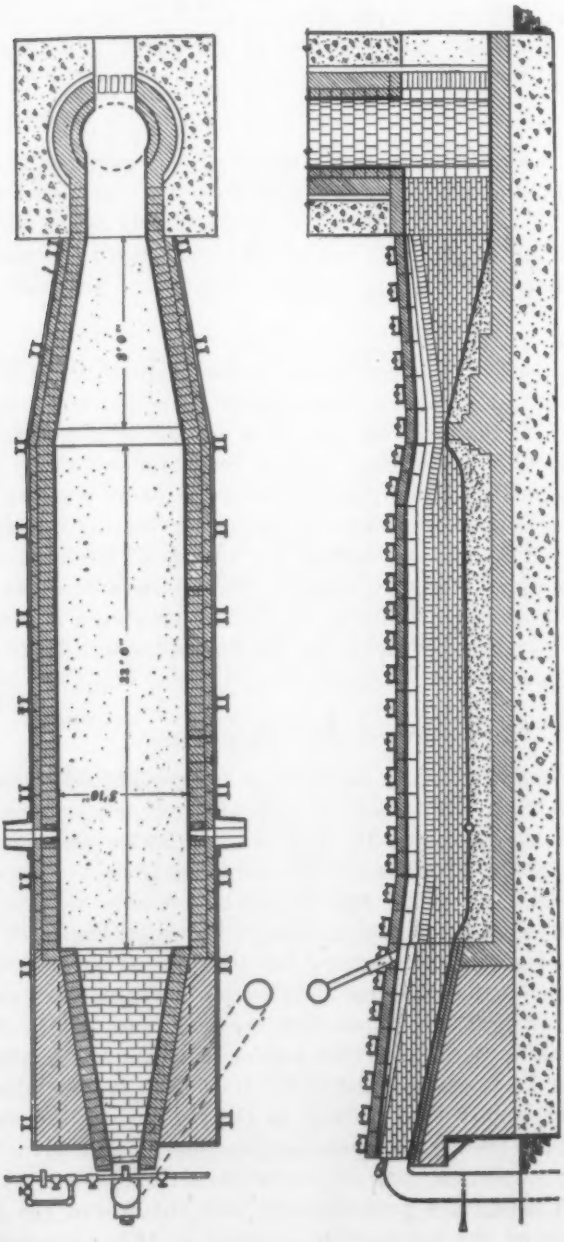

FIG. 1—PLAN AND SECTIONAL VIEW OF 15 TON OIL-FIRED FURNACE.

the hearth, this arrangement being preferred over full width because it affords protection to the sidewalls and reduces the distance between the top blast pipes, thereby promoting a more uniform mixture of the top blast and the burning gases passing through the combustion chamber. The hearth of the furnace is 6 ft. wide and 22 ft. long. The bung line has a gradual slope from its highest elevation to a point midway between the end of the combustion chamber and the tapping hole. The roof above the hearth of the furnace is level and no higher than necessary to accommodate the usual charge. A gentle curve over the rear bridge wall favors a desired deflection of the leaner flame upon the farthest portion of the charge.

10. The size of the rear bridge wall opening is important because it affects fuel consumption and total melting time. A larger opening is necessary when the fuel oil rate per hour is increased for faster melting of a larger charge. When it becomes necessary to lower the furnace bottom to accommodate larger heats, the rear bridge wall is lowered proportionately to permit a corresponding increase in the supply of fuel oil and air required for faster melting. It would also be good practice to lower the furnace bottom without increasing the oil and air supply and the area of the bridge wall opening. While it would take longer to melt a larger charge, the benefit of greater heat utilization throughout the furnace would more than offset the additional heat loss beyond the bridge wall resulting from longer melting time, and the net result would be a lower fuel rate per ton of molten metal without impairing the quality of product or other benefits. On the other hand it would be faulty practice to increase the oil consumption from 160 to 175 gal. per hour and the air supply from 4200 cu. ft. to 4600 cu. ft. per min. without proportionately lowering the bridge wall, because the travel of the gases would be retarded as indicated by back pressure through the skimming doors and bungs and, as a consequence, heat radiation from the brickwork and heat absorption by the charge would be far less effective. The result would be slower melting with an increased amount of oil.

11. The neck of the furnace has two side openings and the stack, only 50 ft. high and 3 ft. inside diameter, has a checker opening opposite the neck. The function of the checker opening is to prolong the life of the stack lining. A metal cover for the checker opening is available in case more draft is desired on exceptional occasions. A low stack is a decided advantage because relatively slight drafts are required for oil burning as compared

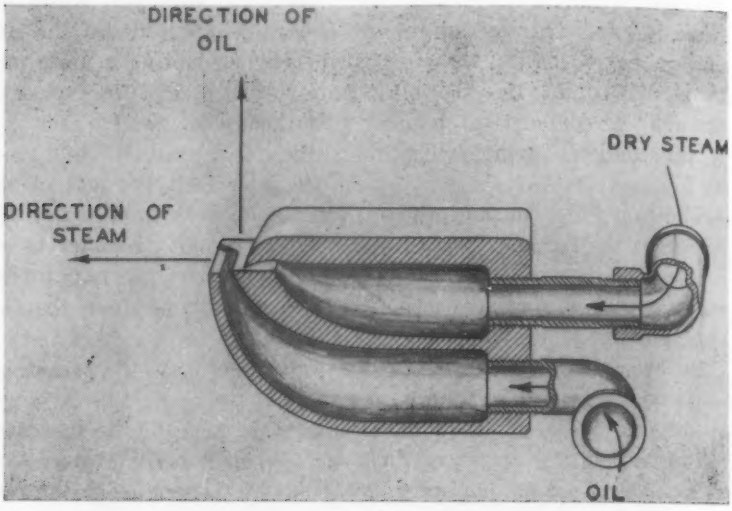

FIG. 2—CROSS SECTION OF EXTERNAL MIXING TYPE OIL BURNER.

with solid fuels. Furthermore, a low stack permits a large bridge wall opening, a desirable feature because radical baffling at the rear bridge wall interferes with radiation of heat to the metal.

THE OIL BURNER

12. Only one high pressure burner is needed for firing purposes. This burner, shown in Fig. 2, is of the fantail external mixing type. It is simple to operate, control and maintain, and it lasts for years. The oblong fuel and atomizing openings are independent of each other and the possibility of clogging or carbon deposit at the oil orifice is very remote. The steam used for atomizing meets the oil at a right angle as it leaves the mouth of the burner and a thoroughly atomized fan shaped flame, corresponding to the shape of the long combustion chamber, is produced. Air, at fairly low pressure, is admitted through a 12-in. nozzle below the burner in quantities barely sufficient to produce the first product of combustion. Even a tendency towards carbonization against the combustion chamber roof or slight backfiring toward the burner is tolerated without concern. A steam pressure of 40 to 50 lb. is sufficient to atomize the fuel and give proper velocity to the burning mixture.

13. The oil is delivered from a large storage tank to a small underground tank near the fuel pump. A one-in. copper steam

pipe inside the underground oil pipe line connecting these tanks furnishes ample heat to reduce the viscosity of the oil to assist gravity feeding. The oil is then pumped from the small underground tank through a twin strainer into a small preheating tank provided with an air cushion. The pulsation effect caused by the strokes of the pump is thus eliminated and a constant and steady pressure at the burner insured. The oil and steam supply pipes leading to the burner are encased side by side in one insulating cover. A temperature of about 130°F., as indicated by the thermometer on the oil line near the burner, seems sufficient to reduce the viscosity of the oil for effective atomization.

THE FLOW METER

14. The meter body of a flow meter is installed near the small preheating tank and the indicating instrument is located near the burner. The flow meter is considered indispensable for uniform

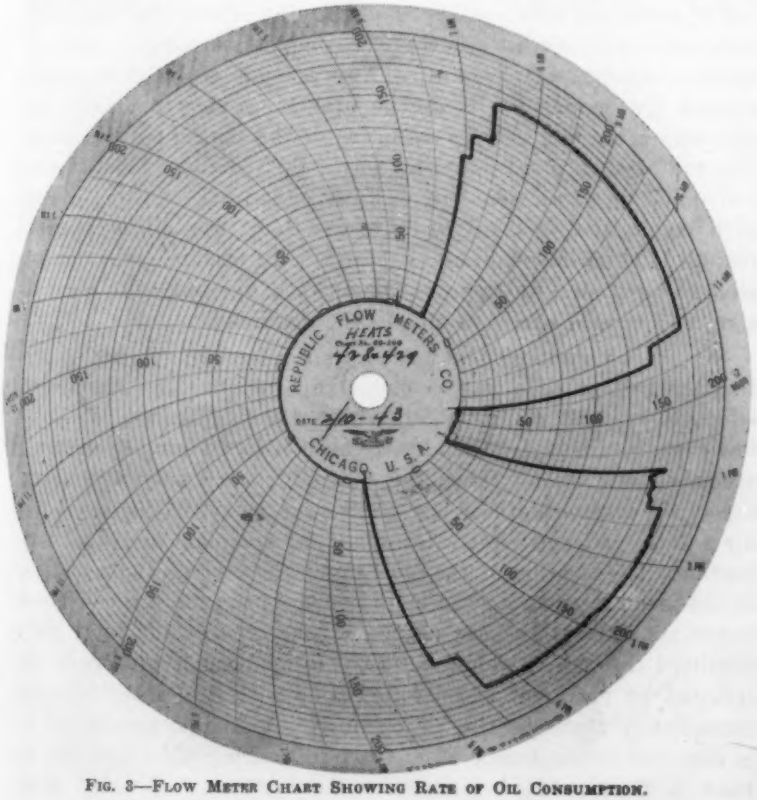

FIG. 3—FLOW METER CHART SHOWING RATE OF OIL CONSUMPTION.

results. The indicator responds quickly to manipulation of the oil valve near the burner and indicates the actual oil rate per hour which is kept constant from the time the furnace has attained sufficient heat for proper combustion until the heat is ready to pour. The chart of Fig. 3, taken from the recording instrument located in the laboratory, shows the log of two daily heats. As shown thereon, the oil consumption is increased to the desired rate per hour after approximately one-half hour of firing and then maintained until the heat is ready for tapping. The rate of oil is then reduced to an amount sufficient to maintain proper temperature of the molten metal.

TOP BLAST IMPORTANT

15. The top blast, or secondary air supply, is considered necessary in oil melting. The practice is sound because complete mixing of gases one with another is a difficult problem and results depend upon the nearest approach to complete combustion with the smallest amount of excess air. Any air not required to supply oxygen for combustion is detrimental, since it will absorb heat and may cause unnecessary oxidation of the elements in the metal. The top blast, properly applied, solves that problem. The theoretical quantity of air required to furnish enough oxygen for complete combustion is about 14 lb. to one lb. of fuel oil, or approximately 1400 cu. ft. of air per gal. of oil. In practice, it is not possible to burn oil with the exact quantity of air but, with good design, 25 per cent excess should be the maximum.

16. It is very important to deliver the top blast in such a way that the best possible contact of air and fuel results. The desired effect is brought about by admitting the overhead blast under low pressure through a suitable number of large bung openings of special construction. Since these openings are only 4-in. apart across the entire width of the combustion chamber, the secondary air will spread and penetrate evenly for complete and final combustion. The location of the blow bung, the correct angle and size of the seven tuyeres, as well as proper air pressure, are considered important factors because nearly 50 per cent of the total air is admitted through the blow bung. The top blast is uniformly distributed by means of a controlled slide with graduated openings immediately above the tuyere openings. A definite amount of air is admitted continuously from start to pouring time and the top blast is then reduced to balance the lowered fuel rate. Heats

Table 1

LABORATORY REPORT ON
11 CONSECUTIVE HEATS RUN FROM OIL-FIRED FURNACE*

		Charge					Oil		Time				Hard Iron Composition, per cent					Oxidati per cent	
Date 1943	Heat No.	Pig, per cent	Sprue, per cent	Malleable Scrap, per cent	Steel, per cent	Lb.	Gal. Oil Used	Gal. Per Ton	Heat Tapped At	Melting Time Hr.	Melting Time Min.	Tons Per Hr.	Silicon	Manganese	Total Carbon	Sulphur	Phosphorus	Silicon	Manga
1/18 AM	391	44	54		2	27000	940	69	10:55	4	0	3.4	1.15	0.33	2.22	0.042	0.132	0.21	0.1
1/18 PM	392	46	48		6	30000	860	57	4:30	3	35	4.2	1.13	0.29	2.38	0.040	0.132	0.22	0.1
1/19 AM	393	44	50		6	29000	920	63	10:55	4	0	3.6	1.03	0.29	2.24	0.043	0.138	0.32	0.1
1/19 PM	394	44	50		6	29500	820	56	4:30	3	35	4.1	1.10	0.30	2.10	0.041	0.138	0.25	0.1
1/20 AM	395	44	54		6	29000	910	62	10:55	4	0	3.6	1.03	0.29	2.35	0.041	0.138	0.34	0.1
1/20 PM	396	46	48		6	29000	810	56	4:25	3	30	4.1	1.12	0.29	2.25	0.041	0.138	0.29	0.1
1/21 AM	397	46	48		6	30000	930	62	11:00	4	5	3.7	1.11	0.29	2.20	0.042	0.138	0.30	0.1
1/21 PM	398	46	48		6	30000	810	54	4:30	3	35	4.2	1.13	0.31	2.43	0.042	0.132	0.24	0.1
1/22 AM	399	44	52		4	29500	910	62	10:55	4	0	3.7	1.08	0.30	2.34	0.042	0.134	0.26	0.1
1/22 PM	400	44	47	3	6	28500	780	57	4:25	3	30	4.1	1.10	0.28	2.26	0.042	0.146	0.23	0.1
1/23 AM	401	46	50		4	29500	930	63	10:55	4	0	3.7	1.02	0.27	2.35	0.043	0.141	0.32	0.2
Average		45	50		5	29182	875	60		3	48	3.8	1.09	0.29	2.29	0.041	0.137	0.27	0.1

* Present daily schedule: 7:30 to 11:30 A.M.—1:00 to 5:00 P.M. Tapping time: 10:55 A.M. and 4:25 P.M.

Table 1

LABORATORY REPORT ON
1 CONSECUTIVE HEATS RUN FROM OIL-FIRED FURNACE*

al. er on	Time — Heat Tapped At	Time — Melting Time Hr.	Time — Melting Time Min.	Tons Per Hr.	Hard Iron Composition, per cent — Silicon	Manganese	Total Carbon	Sulphur	Phosphorus	Oxidation, per cent loss — Silicon	Manganese	Carbon	Physical Tests — Tensile Strength, lb. per sq. in.	Elongation, per cent in 2 in.
9	10:55	4	0	3.4	1.15	0.33	2.22	0.042	0.132	0.21	0.13	0.74	55640	23.00
7	4:30	3	35	4.2	1.13	0.29	2.38	0.040	0.132	0.22	0.18	0.55	53680	22.00
3	10:55	4	0	3.6	1.03	0.29	2.24	0.043	0.138	0.32	0.19	0.57	54350	25.00
6	4:30	3	35	4.1	1.10	0.30	2.10	0.041	0.138	0.25	0.16	0.67	57240	28.00
2	10:55	4	0	3.6	1.03	0.29	2.35	0.041	0.138	0.34	0.16	0.45	53340	24.50
6	4:25	3	30	4.1	1.12	0.29	2.25	0.041	0.138	0.29	0.19	0.51	54810	25.00
2	11:00	4	5	3.7	1.11	0.29	2.20	0.042	0.138	0.30	0.18	0.52	56280	25.00
4	4:30	3	35	4.2	1.13	0.31	2.43	0.042	0.132	0.24	0.17	0.41	54320	19.50
2	10:55	4	0	3.7	1.08	0.30	2.34	0.042	0.134	0.26	0.16	0.38	55900	25.00
7	4:25	3	30	4.1	1.10	0.28	2.26	0.042	0.146	0.23	0.18	0.58	55360	25.50
3	10:55	4	0	3.7	1.02	0.27	2.35	0.043	0.141	0.32	0.20	0.50	53650	23.00
0		3	48	3.8	1.09	0.29	2.29	0.041	0.137	0.27	0.17	0.53	54960	24.14

.M. and 4:25 P.M.

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ranging from 13 to 16 tons are handled with 4700 cu. ft. of air per min. and 170 gal. of oil per hour. Smaller heats are run with a 4200 cu. ft. of air and 150 gal. of oil ratio. These figures indicate that the excess air runs less than 20 per cent above theoretical requirements.

THE CHARGE

17. As shown in Table 1, the charge consists of approximately 45 per cent of pig iron, 5 per cent of short steel rails and 50 per cent of sprue and remelt. No malleable scrap, other than rejected castings or customers' returns, has been used for many years. Taking into consideration the amount of rust, usually underestimated, and the bulkiness of agricultural malleable scrap, as well as the uncertainties of its composition, the savings often claimed may well be discounted. Steel rails on the other hand are compact, easily handled, of definite composition and free from detrimental impurities. A reasonably compact charge, properly distributed, is most desirable because, aside from easier handling, it permits a lower bung line which enables faster melting through better heat absorption by the charge.

MELTING THE CHARGE

18. The melter's most important aim is to produce a molten metal with the desired composition and the proper temperature by the time the heat is scheduled for tapping. Ordinarily, heats do not vary much in size throughout the week, and it is not necessary, therefore, to manipulate the oil rate and the air requirements from day to day. By stabilizing the three items of greatest importance —(1) *the charge,* consisting of uniform melting stock, (2) *oil,* injected in a definite amount and (3) *the air,* admitted in known quantities—the influence of the human element becomes eliminated to a great extent.

19. An experienced melter knows how to distribute his charge and is aware of variations that affect melting, such as furnace wear, possible bottom trouble or even weather conditions. He is confident, however, that, through proper and timely use of the rabbling pole and the skimmer, uniform results can be maintained.

20. The charge is deposited through two bung openings. Approximately two-thirds of the sprue, all the steel and less than half of the pig iron is scattered well toward the front, and the bulk of the pig iron is charged on top of the balance of the sprue further back. Considerable scattering is necessary because the

inside height of the furnace, averaging 36-in. at the center line for 15 ton heats, is kept as low as possible for greater melting efficiency.

21. When skimming time approaches, the partially melted metal is disturbed and rabbled with poles bought for that purpose. This thorough mixing promotes uniform melting and permits earlier skimming. When the heat is almost ready, the first test sprues are poured and broken to determine how close the metal is to the desired analysis. Occasionally, a section of the furnace bottom causes minor trouble and it may be advisable then, or even necessary, to dope the heat with a small amount of ferrosilicon to raise the silicon content a few points. Preliminary analyses are not considered necessary, because it is not difficult to maintain a chemical composition within practical limits. The second tests are poured shortly after the first tests and if the timing of the test ladle verifies that the molten metal is as hot as desired, tapping begins. A little later on, when pouring is in full sway, the top blast is reduced and the oil turned down, as shown on the flow meter chart in Fig. 3.

22. Table 1 shows the laboratory record of 11 consecutive heats, or one week's run, from one furnace. It is shown thereon that the morning heats, of approximately 15 tons, require 4 hours melting time (the half-hour pouring time not included), as compared with 3½ hours melting time for the afternoon heats. The oil consumption, averaging 60 gal. per ton, runs proportionately higher for the morning heats.

Oxidation

23. The silicon and manganese losses for the heats shown in Table 1 average 27 points and 17 points respectively, while the carbon loss amounts to 53 points. The phosphorus content remains the same and the sulphur invariably runs between 0.04 and 0.045 per cent. The Monday morning heat, made on a new sand bottom, loses more carbon and less silicon and manganese than the following heats, but this is taken care of in the charge by using a smaller amount of steel. The oxidation of silicon and manganese goes hand in hand and takes place soon after the heat starts melting. The degree of basicity and acidity of the slag indicates if the loss of these elements is moderate or somewhat high. The carbon reduction is not associated with silicon and manganese oxidation. Excessive carbon losses can be attributed to low fuel-high air ratios, too high top air pressures, faulty top blast application or an

oxidizing atmosphere after skimming or during the pouring period. Very small heats, melted on a large hearth area, ordinarily lose more carbon, but this is compensated for by reducing the amount of steel in the charge. Possible high oxidation of silicon and manganese, because of small heats and a shallow bath, is counteracted by fast melting and quick superheating. By protecting the shallow bath with a reducing atmosphere as soon as the heat is ready for pouring, excessive carbon losses of small heats are prevented. A slight turn of the oil valve or a mere change of the position of the lever controlling the overhead blast openings does the trick.

24. Excessive oxidation, caused by the bessemerizing effect of too high top air pressure, is not tolerated. Very attractive fuel oil rates can be obtained from such faulty practice but accumulative troubles will follow. The melters have been impressed with the fact that quality and uniformity of product and regularity of the tapping schedules are of much greater importance than reduced oil rates.

25. Weekly averages of 55 gal. of oil per ton of metal charged are readily obtained without resorting to harmful oxidation. The better fuel rate is brought about by reducing the bridge wall opening, the oil consumption, and the top and bottom blast, resulting in better heat utilization through greater heat absorption by the charge and in a smaller heat loss beyond the bridge wall. The silicon and manganese loss will run a few points higher, but this is not at all objectionable. It will, however, take somewhat longer to melt the heat but, since it is more important to maintain the desired time schedule, fuel consumption is of secondary importance. The fuel consumption for the past 3 months' heats, averaging 14 tons, is 60 gal. per ton melt, the oil costing 4.5c per gal. delivered at the plant.

TWO HEATS PREFERRED

26. Larger heats offer very little economy as far as fuel consumption, furnace operating and repair labor and refractory costs are concerned. Experience has also proven that the molder's production decreases considerably when his pouring capacity is overtaxed. The smaller floor spaces permit closer grouping around each furnace and, therefore, quicker handling of the molten metal. The sand cutting problem, on the other hand, is considered a decided disadvantage because of the limited time available for sand cutting during the noon period. In operating the two-heat sched-

ule, 3½ hours are devoted to molding and a half hour to pouring during each morning and afternoon period. A 1½ hour noon intermission, now in effect, solves the sand cutting problem and allows ample time for melting the afternoon heat.

REFRACTORIES AND REPAIRS

27. The air furnace requires such a great amount of maintenance work and materials that the importance of refractories cannot be overlooked. The skillful melter is aware that he can effect considerable economy by prolonging the life of the sidewalls and bungs by proper installation of the brick, by reclaiming and utilizing worn materials and by devoting attention to bung handling and location. The manufacturers of fire brick are also aware of the severe conditions their product is subjected to. They understand malleable furnace requirements and deserve credit for their efforts towards improvement of the quality and uniformity of suitable refractories.

28. More or less extensive overhauling is required each week-end, for, in addition to removal and replacement of the sand bottom, approximately 40 lb. of refractories, or 5 9-in. equivalents of brick, have been destroyed for every ton of iron melted. The front half of each sidewall needs replacing every 2 weeks and the sidewalls beyond, every 4 weeks, aside from batting up wherever necessary to even up with partial front sidewall replacements. Sidewall brick, as well as the bungs, are laid up in fireclay slush and the gaps between bungs and bats are luted with the crushed salvage of discarded bungs mixed with fireclay. The combustion chamber walls seldom require attention, with the exception of the ends, which need replacing every 4 weeks. First quality brick is necessary for sidewall construction. This brick must be dense to resist erosion, tough to resist abrasion and spalling and refractory to withstand high temperatures.

29. The bottom of the furnace is taken up each week-end and renewed with additions of washed silica sand. Coarse sand is avoided, as it lends itself to deeper fusing, which would require more replacement material. The new bottom is protected with a bedding of straw before charging the Monday morning heat. The brick bottom has been tried but abandoned because its economy is questionable when small to medium size heats are the rule.

30. The life of the bungs is interesting, all the more so because of the wide variance of results in different foundries. Figure 4

illustrates the results obtained as tabulated from continuous individual bung records. All bungs are numbered when first placed on the furnace and given a letter, corresponding to the position on the furnace. This letter is changed whenever it is deemed advisable to move the bung towards the rear for greater life. This system has been used for many years and has proven valuable because, in addition to the accurate service information obtained, it stimulates interest and responsibility on the part of the melter, resulting in lower refractory costs. Due to great variance in the size of furnaces and heats, the life of the bungs should, for comparison, be interpreted in terms of tons melted rather than the number of heats, for, obviously, shorter bungs, serving smaller heats, should last longer. As shown on the diagram, the majority of the bungs are 18-in. wide and made up of 9-in. arch brick, which are more economical than the 13½-in. bung brick and last fully

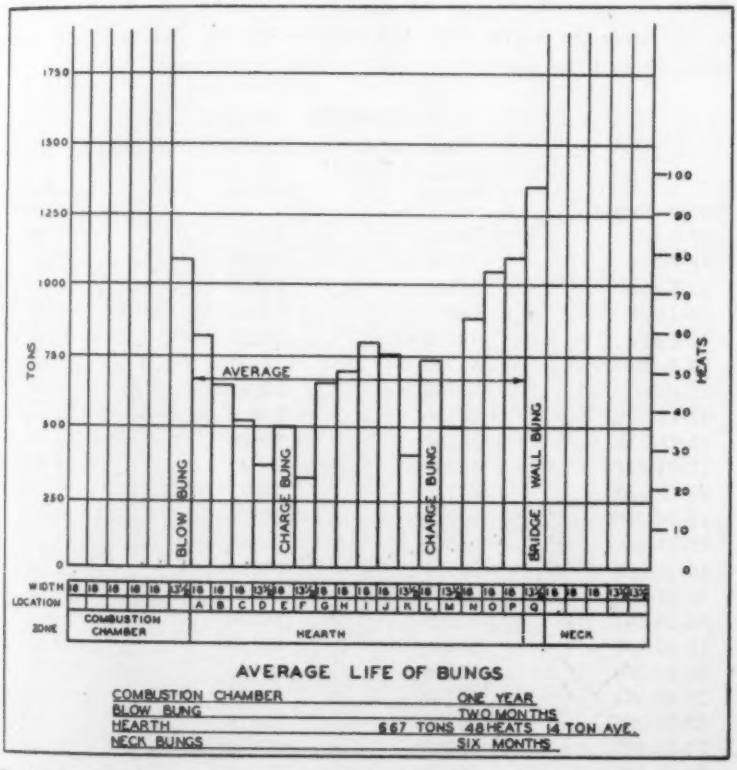

FIG. 4—DIAGRAM SHOWING LIFE OF BUNGS OF OIL-FIRED MELTING FURNACE WITH AVERAGE HEAT OF 14 TONS.

as long. The bungs on each side of the charging bungs are of the 13½-in. size. These bungs are abused through contact with portions of the charge and the bars used for scattering purposes. Mechanical strength of the brick, therefore, is more desirable than in the case of the 18-in. bung, which has been improved considerably by imparting greater density and, therefore, more strength without impairing spalling resistance. The 13-in. bung formerly used has, in the interest of simplification, been substituted with the more practical 13½-in. standard, which is better suited from the equivalent angle and should, therefore, replace the 13-in. series.

31. Approximately 35 lb. of silica sand per ton of metal charged is needed for weekly bottom additions and an average of 11 lb. of fireclay per ton of metal charged for refractory replacements. The fire brick requirements average 2 9-in. equivalents for bungs and 3½ bricks for sidewall replacements, or a total of 5½ 9-in. equivalents per ton of metal charged. As shown in Fig. 4, the average bung over the hearth serves 667 tons of metal charged and the average life is 48 heats of 14 tons.

Table 2

CERTIFICATE OF TESTS

Samples Marked	*Ultimate Strength, lb. per sq. in.*	*Yield Point, lb. per sq. in.*	*Elongation, per cent in 2-in.*
12-1-321	55640	36810	27.50
12-2-324	54800	36690	25.00
12-3-326	54530	36390	20.00
12-4-328	54660	36860	24.00
12-7-330	54400	36420	21.50
12-8-332	55740	36480	25.00
12-9-335	54680	35900	22.50
12-10-337	55380	36620	22.50
12-11-339	53980	36600	20.00
12-14-341	55640	36540	27.50
12-15-343	54740	35970	25.00
12-16-346	56020	36910	25.00
12-17-348	54310	36500	21.50
12-18-350	54080	36100	21.50
12-21-353	55060	36350	25.00
12-22-355	55020	36290	24.00
12-23-357	54840	36120	28.50
12-24-358	55770	37100	25.00
12-28-361	55710	36670	25.00
12-29-362	56220	36810	27.50
12-30-365	55940	36650	25.00
12-31-367	56280	36840	25.00
Average	55156	36528	24.25

Table 3

EFFECT OF SILICON AND CARBON ON TENSILE STRENGTH, YIELD POINT AND ELONGATION*

Silicon Range, per cent	*Carbon Range, per cent*	*Average Silicon, per cent*	*Average Carbon, per cent*	*Total Silicon and Carbon, per cent*	*Average Strength, lb. per sq. in.*	*Average Yield Point, lb. per sq. in.*	*Average Elongation, per cent in 2-in.*	*No. Bars*
1.10 to 1.20	1.90 to 2.00	1.15	1.95	3.10	57350	37220	26.00	5
	2.00 to 2.10	1.15	2.05	3.20	56470	36770	26.50	10
	2.10 to 2.20	1.15	2.15	3.30	56230	36820	25.50	24
	2.20 to 2.30	1.15	2.25	3.40	55200	36610	24.00	33
	2.30 to 2.40	1.15	2.35	3.50	54220	36290	22.50	34
	2.40 to 2.50	1.15	2.45	3.60	53910	36510	21.00	16
	2.50 to 2.60	1.15	2.55	3.70	51970	35470	18.50	3
1.00 to 1.10	1.90 to 2.00	1.05	1.95	3.00	56460	36820	24.50	2
	2.00 to 2.10	1.05	2.05	3.10	55800	36750	26.00	8
	2.10 to 2.20	1.05	2.15	3.20	55420	36850	25.50	22
	2.20 to 2.30	1.05	2.25	3.30	55340	36540	25.00	34
	2.30 to 2.40	1.05	2.35	3.40	54270	36340	23.00	30
	2.40 to 2.50	1.05	2.45	3.50	54070	36340	22.00	11
	2.50 to 2.60	1.05	2.55	3.60	53100	36440	20.50	6
	2.60 to 2.70	1.05	2.65	3.70	52370	36170	19.50	4
0.90 to 1.00	2.00 to 2.10	0.95	2.05	3.00	55980	37140	27.00	2
	2.10 to 2.20	0.95	2.15	3.10	54900	36590	24.00	6
	2.20 to 2.30	0.95	2.25	3.20	54550	36510	23.00	10
	2.30 to 2.40	0.95	2.35	3.30	54300	36580	22.50	17
	2.40 to 2.50	0.95	2.45	3.40	53540	36470	21.50	16
	2.50 to 2.60	0.95	2.55	3.50	52760	36200	19.50	6
	2.60 to 2.70	0.95	2.65	3.60	50840	.....	17.00	1

* Results compiled from test bars of 300 different heats.

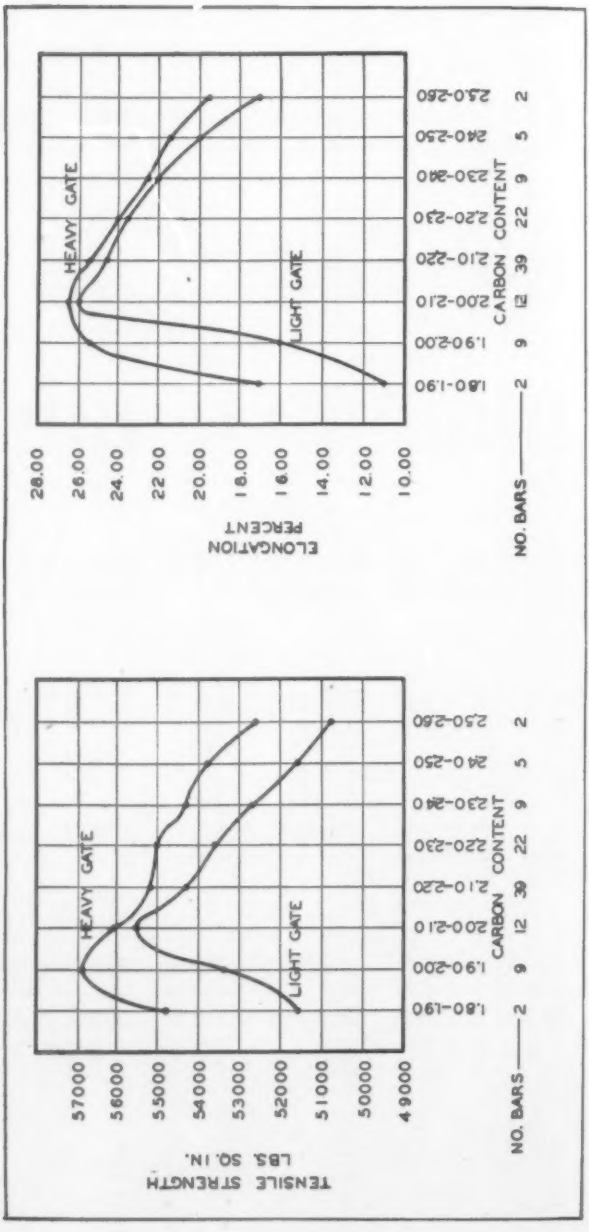

FIG. 5—EFFECT OF CARBON ON SHRINKS.

PHYSICAL TESTS

32. Frequently, requests are made by customers for test bars and certifications showing that the product conforms with the minimum requirements of Federal Specification No. QQI-666, which is identical with the A.S.T.M. Specification No. A 47-33 for Grade 35018. Table 2 illustrates a monthly certificate of tests on daily bars. All bars shown on this report pass the Grade 35018 requirements, which call for a tensile strength of 53,000 lb. per sq. in. and a yield point of 35,000 lb. per sq. in., with an elongation in 2-in. of 18 per cent. Similar results are regularly obtained.

33. Table 3 indicates the approximate tensile properties that are expected from test bars with a silicon content of 0.90 to 1.20 per cent and a carbon range of 1.90 to 2.70 per cent. It is shown in this table that excellent tensile properties are obtained with the preferred 3.20 to 3.50 silicon-carbon ratios. It can also be noted that if the silicon runs 10 points higher and the carbon 10 points lower, the combined per cent of silicon and carbon being the same, the ultimate strength will average 1000 lb. higher. This table is a composite of test bars from 300 different heats and, therefore, considered representative.

34. The effect of low carbon on shrinks, an important subject frequently discussed, has been given much consideration. Some contend that shrinks become more prevalent as the carbon content decreases, while others claim that high oxidation rates or high pouring temperatures are more responsible. The graph of Fig. 5 shows the difference in tensile strength and elongation of two sets of bars poured with the last metal from 100 heats. The gates of one of these standard test bars were reduced to $\frac{1}{8}$-in. thickness to interfere with feeding, while the gates on the opposite bar of the same gated pattern were left $\frac{5}{16}$-in. thick for proper feeding. It was assumed that a noticeable difference in tensile strength and elongation would result, varying with the degree of shrink within the bars with light gates, as compared with the bars with the regular heavy gates. The data shown in Fig. 5 could be condensed in three groups as follows:

Group	*No. Bars*	*Carbon Range, per cent*	*Tensile Strength Heavy Gate, lb. per sq. in.*	*Tensile Strength Light Gate, lb. per sq. in.*	*Difference, per cent*	*Elong. Heavy Gate, per cent in 2-in.*	*Elong. Light Gate, per cent in 2-in.*	*Difference, per cent*
1	11	1.80 to 2.00	56530	53090	6.1	24.00	15.00	37.5
2	82	2.00 to 2.40	55160	54120	1.9	25.00	24.00	4.0
3	7	2.40 to 2.60	53500	51400	4.0	21.00	19.00	9.6

It is interesting to note that the tensile properties are the least affected on the 82 bars with a carbon content ranging from 2.00 to 2.40 per cent. In fact, the smallest difference in tensile strength and elongation occurred on the 12 bars within the 2.00 to 2.10 per cent carbon range. Of the bars in Group 1, (carbon content 1.80 to 2.00 per cent) the alarming variation occurred on the 8 bars with a carbon-silicon total below 3.00 per cent, resulting from excess oxidation of the last metal of the heats from which these bars were poured. Judging from the above indirect test, there is no indication that low carbon, if accompanied by a suitable silicon content to keep the total silicon and carbon above 3.00 per cent, will cause more shrink. If, on the other hand, the silicon-carbon ratio of 3.00 per cent total or less is due to an unduly oxidized metal, internal shrinks will be very much in evidence.

35. The above references to the effect of low carbon on shrink are not conclusive, but the information obtained is, nevertheless, of value and a more thorough investigation should prove if the contentions are correct. A similar study to determine the effect of low carbon, high pouring temperatures, high oxidation rates or unduly oxidized metal on cracks would also be worth while.

CONCLUSION

36. A considerable number of malleable plants have practiced oil melting with varying degrees of success. Each foundry, in the absence of reliable information, attempted to solve its problems in its own way. The furnace change from hand firing to oil seemed quite simple, but difficulties in maintaining a correct furnace atmosphere proved hard to overcome, especially when handicapped with the disadvantage of high stacks. Attractive fuel rates were frequently accompanied by excessive oxidation. High fuel rates, on the other hand, would often be followed by unruly schedules. Oil is, nevertheless, an excellent fuel. The disadvantage of high fuel cost is compensated for by numerous advantages, its use permits simplified handling and storage and, with proper application of suitable air and fuel ratios and partial elimination of the human element through the use of a flow meter, very uniform results are regularly and consistently obtained.

DISCUSSION

Presiding: D. P. FORBES, Gunite Foundries Corp., Rockford, Ill.

Co-Chairman: CARL F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

D. I. DOBSON[1]: We happen to be melting with oil, and I have one furnace connected to a 270 ft. stack. I have two other furnaces connected to approximately 70 ft. stacks, and the furnace connected to the high stack seems easier to control on the oxidation losses than the ones on the lower stack. What is Mr. Van Lantschoot's theory on the low stack as far as effective oxidation is concerned?

MR. VAN LANTSCHOOT: Since oil is a very constant and flexible fuel, with a much greater number of heat units per lb., as compared with coal, low pressures and a low stack are necessary for uniform results, and for effective heat utilization resulting in fuel economy. I really do not know what the effect of a high stack would be on oxidation.

W. R. JAESCHKE[2]: Mr. Van Lantschoot, in talking about the economics of oil firing compared with pulverized coal, at 4½c per gal. and 60 gal. per ton, that is a fuel cost of $2.70 per ton of iron melted. I think there are plenty of coal-operated furnaces which are doing it for about $1 a ton less than that.

This does not take into consideration the lower percentage of pig iron, which is a cost item in a normal metal market. Some plants, operating two heats a day, are averaging very close to 600 lb. of coal to the ton. I do not believe any are paying over $6.00 per ton of coal.

MR. VAN LANTSCHOOT: I agree with you that the fuel cost is greater in oil firing. Figuring coal at $6.00 per ton and oil at 5c per gal., the B.t.u. cost of the oil runs about 50 per cent higher. However, I feel that through greater heat utilization the 50 per cent higher cost can be reduced by 20 per cent, leaving the actual fuel cost only 30 per cent higher than with coal.

MR. JAESCHKE: I do not believe that there are any coal operators here using as high as 45 per cent pig iron in the charge, and that is quite a cost item in a normal market.

MR. VAN LANTSCHOOT: That is true. On the other hand, we cannot overlook the 10, 15 or even 20 per cent of rust adhering to malleable scrap. I refer to the type of malleable scrap available in our locality. Furthermore, if we used a considerable quantity of malleable scrap in the charge, we would have to raise the bung line to accommodate the bulkier charge. The lower the bungs, the better the results.

I do not contend in my paper that oil can be used more economically than coal from the standpoint of fuel cost. It would probably run 30 per cent higher.

MR. JASECHKE: I got that impression from your reference to the B.t.u. per ton. Figuring the B.t.u. value of coal, I think you will find most generally a heat input down nearer to 8,000,000 B.t.u. per ton. I think the B.t.u. value of your fuel oil in gal. of fuel used will

[1] General Malleable Corp., Waukesha, Wisc.
[2] Whiting Corp., Harvey, Ill.

bring your heat input higher than that.

MR. VAN LANTSCHOOT: I am figuring coal at 14,000 heat units per lb., and oil at 145,000 heat units per gal. If the coal costs $6.00 per ton and the oil 5c per gal., then the heat unit cost of the oil would be 50 per cent higher.

CHAIRMAN FORBES: I would like to add, for the purpose of the record, an interesting test we ran some time ago. It may throw some light upon the problems of combustion in an air furnace. Due to the fact that we have not used oil for melting for about 15 yrs. and, because I cannot locate the exact data, there may be some errors. However, the facts are substantially correct.

We had experienced excessive oxidation of metal in our air furnaces, particularly when the heats were of the small size, with the result that, even though the metal was hot, misruns were troublesome and castings seemed to crack excessively. The tests were conducted in a 25-ton capacity oil-fired air furnace with a hearth 8 ft. wide and approximately 25 ft. long. We were melting from 16 to 18 tons in this furnace.

The burner arrangement was substantially as described in today's paper, and we were producing a metal in the range from 2.30 to 2.50 per cent carbon and .90 to 1.05 per cent silicon. We had an idea that the melting conditions close to the burner were different from those near the stack, and to test this out we constructed a temporary bridge wall across the furnace at the center of the hearth.

The top of the bridge wall was a fraction of an in. above the expected slag line. We then made two identical 8-ton charges, one of which was placed in the front of the furnace, at the burner end, and the other placed at the back of the furnace, near the stack. In a relatively short time melting commenced, and the front charge was reduced to a fluid. Melting at the back proceeded very slowly, and the metal at the front was almost hot enough to pour before any appreciable amount of melting occurred at the back.

We continued to fire, eventually reducing the back charge to a pasty mass. A test sprue poured from the front of the furnace showed a completely gray structure, and, if I remember correctly, analyzed about 2.85 per cent carbon, 1.50 per cent silicon and .43 per cent manganese. Sample ladled out of the rear gave an analysis of 1.65 per cent carbon, .60 per cent silicon and .14 per cent manganese.

We added enough steel to make the metal from the front usable. As soon as this was tapped out, we broke up the bridge wall with bars, drained the metal to the front of the furnace, and added enough high silicon pig iron to restore fluidity so that we could drain the furnace and pig this material. As a result of this experience, we shortened the hearth of our oil-fired furnaces substantially, and apparently improved our melting conditions.

We have the opinion that an oil-fired flame is something like a bunsen burner in its effect. The flame close to the burner is hot and reducing, whereas the flame at the tip is slightly cooler and highly oxidizing.

While we do not know whether the same condition holds true with respect to pulverized coal, and the cost of a test has deterred us from

determining it, we do suspect that the same condition, possibly less serious in degree, would hold true for any type of fuel used in the air furnace.

MR. VAN LANTSCHOOT: We have also run into troubles and problems that had to be worked out. However, I feel that by reducing the air pressure, by keeping the volume of the blast to a minimum, and by using a large bridge wall opening and a low stack, uniform melting and proper results will be obtained. I am of the opinion that a high stack will produce localized melting to a greater extent than a low stack. What was the height of your stack?

CHAIRMAN FORBES: I would say 65 or 75 ft.

MR. VAN LANTSCHOOT: That is too high.

CHAIRMAN FORBES: The thing I cannot understand is why there was less oxidation in the front, where you would expect the bessemerizing effect and more O_2—at least I should think you would—and, nevertheless, the oxidation was much greater at the back, near the stack.

M. E. MCKINNEY[3]: It is interesting to note that, if you had been able to get the two heats together, you would have achieved the exact analysis you were seeking.

DAVID TAMOR[4]: Did you have a combustion chamber in the furnace, and did it follow the contour of the flame?

CHAIRMAN FORBES: Yes. Our primary air entered the furnace through a pipe about 15 in. in diameter and it had a long, straight section. It came over a gangway at a slight angle instead of coming in at a short elbow. We found too much turbulence in a short elbow. The combustion chamber was about 8 ft. long, similar to that described in the paper.

FREDERICK WURSCHER[5]: In running this comparison of test bars with heavy and small gates, to what do you attribute the difference of higher physical properties on the wide gate in relation to the small gate?

MR. VAN LANTSCHOOT: I purposely reduced the two gates on only one of the two test bars gated together to produce shrink in that bar, by interfering with actual feeding.

MR. WURSCHER: You are not certain that you had a shrink?

MR. VAN LANTSCHOOT: There could not have been very much shrink, as indicated by the slight difference in the tensile properties of the fed and unfed bars. I tried to determine whether low-carbon metal would produce more shrink than a higher carbon metal, which has been mentioned repeatedly. If this contention is true, I naturally assumed that in the low carbon bars the shrink would be greater and, consequently, that the difference in the tensile properties of the fed and unfed bars would be greater.

MR. WURSCHER: It is to be understood that the other bars also had a shrink.

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[3] International Harvester Co., Hamilton, Ont. Canada.
[4] American Chain Malleable Foundry, York, Pa.
[5] Acme Steel and Malleable Iron Works, Buffalo, N. Y.

MR. VAN LANTSCHOOT: The other bars with the normal gate did not have any shrink. That was taken care of by effective feeding.

MR. TAMOR: Did you have an actual white spot in the center of your fractured bar? Very often you will get two bars and both will have a silky, normal fracture at approximately the same strength, but one will have high elongation and the other will have a low one.

Let us say that the good one has an elongation in the neighborhood of 22 to 25 per cent, and then the other might go as low as 15 or 14 per cent. The latter will have a little white spot in it. That little white spot is probably a free carbide which resulted from the anneal; that is, you did not anneal around the shrink and the elongation will drop. Did you ever run into that condition with bars which have not been sufficiently fed?

MR. VAN LANTSCHOOT: The spot to which you refer was in evidence on a few of the bars with a total silicon-carbon content of below 3 per cent. I attribute that particular spot to excessive oxidation and a high pouring temperature rather than low carbon.

MR. TAMOR: We have done some work on phosphorus and found the phosphorus content of extreme importance in duplexing. We ran out of ferro-phosphorus during an interval and the bars showed the white spot. Since the phosphorus is a fluidizer, when we came back to normal phosphorus, the white spots disappeared and the elongation rose to where it should be. I am talking now of the order of 15 to 18 points of phosphorus against 9 to 12 points, as is common in batch melting. We felt sure that the loss of fluidity was due to the lowered phosphorus content as we have not seen these spots since. We refer to an iron of 2.15 to 2.20 per cent in carbon.

MR. VAN LANTSCHOOT: It was very noticeable that the greatest difference in tensile properties occurred on some of the bars with a very low carbon content—a carbon content of 1.8 to 2 per cent. Nearly all of the bars within the low carbon group, but with the regular heavy gates, had a 22 to 26 per cent elongation. On the other hand, the elongation on some of the companion bars with the light gates would run as low as 6 and 8 per cent. These low elongation bars had a very distinct spot in them, although the majority of these bars were sound. I interpreted these spots as a central shrink, and I attribute the reduction in tensile properties to the shrink condition in these unfed bars.

MR. TAMOR: Just what do you mean by a shrink condition? Do you actually mean visible, internal shrink or a change of metal density? Is one metal more porous than the other?

MR. VAN LANTSCHOOT: You must keep in mind that the two bars were gated together. The bar with the regular gate, and therefore properly fed, proved satisfactory; its tensile properties were normal. It was the other bar with the reduced gate, alongside the good, sound bar, that proved defective, and surely it must have been interference with feeding that caused the difference in tensile properties.

Brackelsberg Furnace Melting of Malleable Iron

By W. Zeunik* and Kenneth Mason*, Indianapolis, Ind.

Abstract

The paper discusses the rather recent innovation in this country of melting malleable iron in the Brackelsberg rotary furnace. Included is a description of the furnace, type of refractory lining employed, and general information as to suitable fuel, lining life, melting losses, and fuel consumption. A detailed account of the sequence of operations involved in making a malleable iron heat is followed, touching on method of charging the furnace, rotating procedure, firing rate, and slagging. Emphasis is placed on the importance of continuity of operation for full economy.

1. The first Brackelsberg furnace to be introduced into this country was purchased from the German manufacturers by the Jefferson Union Company, Lockport, New York, in 1929. Shortly thereafter, the American rights to the Brackelsberg furnace were acquired by the Whiting Corporation, and two units were installed in the United States. The first Brackelsberg furnace used for the regular production of malleable iron in this country was installed at the Indianapolis plant of the National Malleable and Steel Castings Company in 1934, and additional units have since been purchased by this company and others.

Description of Brackelsberg Furnace

2. The furnace consists of a cylindrical steel body 14 ft. long and 48-in. in diameter inside the refractory lining, with ends in the form of truncated cones, 3 ft. high and 20-in. in diameter at the small end. Two steel tires are mounted on the shell circum-

* Plant Metallurgist and Malleable Iron Melter, respectively, National Malleable and Steel Castings Co.

Note: This paper was presented at a Session of the Symposium on Malleable Iron Melting at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

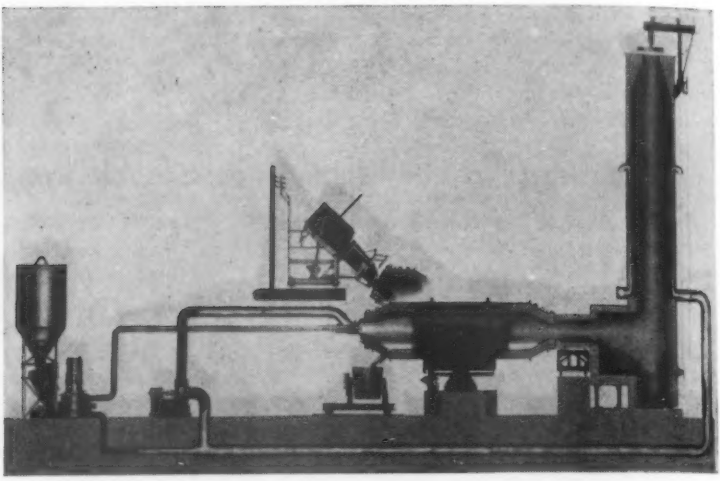

FIG. 1—BRACKELSBERG ROTATING FURNACE, SHOWING PULVERIZER AND BLAST PREHEATING APPARATUS.

ference, each one about 4 ft. from the end of the shell. These tires serve to carry the load and are driven at 4 points by smooth rollers mounted in the operating cradle. The entire furnace can be lifted out of the cradle for repairs or replacement. The furnace can be rotated at a speed of 1.37 r.p.m., and the furnace shell can be tipped about a horizontal axis passing through the center of gravity, for the purpose of charging or repairs. Provision is made for preventing the shell from slipping off of the power rollers when tilting, by 4 other rollers mounted at the corners of the cradle so that they bear on the outside edges of the tires.

3. The Indianapolis furnaces are normally of 5 ton capacity. Firing is by means of pulverized coal through the opening in one end, and the flue gases escape into the stack at the other end.

4. The stack serves the double purpose of conveying furnace exhaust gases and of supplying heat for preheating the air used to burn the fuel. It is lined with special shaped fire clay blocks, designed to allow the passage of air down through the heated blocks of the stack without contamination from the flue gases. A series of vents near the top and outside of the stack provides an entrance for the air to be preheated. After passing down through the hot stack, the preheated air is drawn through insulated pipe to the secondary fan and coal pulverizer.

5. The recuperator is capable of raising the temperature of the

secondary air to 600°F. (316°C.). The advantages of a high air temperature are shorter melting time, higher metal tapping temperatures, and, consequently, lower fuel consumption.

6. The preheated air which passes through the coal pulverizer and is called primary air is held to a maximum of 225°F. (107°C.) in order to eliminate the possibility of the coal coking in the pulverizer or the pipe leading to the burner. The secondary air is brought into contact with the primary air and fuel as they leave the burner.

ANALYSIS OF COAL USED

7. The coal used is of the soft, West Virginia type, ground by the pulverizer so that approximately 90 per cent will pass through a 200 mesh sieve. The approximate analysis of coal being used at present is as follows:

	Per Cent
Volatile matter	20.75
Moisture	1.48
Fixed carbon	72.46
Ash	5.31
B.T.U.	14,980

It has been found from experience that a low volatile coal is necessary for satisfactory performance.

FIG. 2—THREE 8 TON CAPACITY BRACKELSBERG FURNACES. THE FURNACE CHARGES ARE BROUGHT IN IN 5 TON CAPACITY BUCKETS AND PLACED ON CHARGING CAR SHOWN AT LEFT.

FIG. 3—SHOWING METAL CHARGE BEING UNLOADED INTO BRACKELSBERG FURNACE IN CHARGING POSITION.

8. The gas compositions will run from 12.5 per cent to 14.5 per cent CO_2, 0.2 per cent to 2.0 per cent O_2 and 0.4 per cent to 1.8 per cent CO, the balance N_2 and small amounts of H_2O, with traces of H_2. Slag analyses may be somewhat inconclusive due to inclusions of refractories, coke, etc., floating in the slag. It is believed that the slag itself, exclusive of contamination, would contain approximately 50 per cent SiO_2, 42 per cent FeO and 8 per cent MnO.

REFRACTORIES

9. Various types of refractories have been used by different operators, but at present a silica brick service lining is employed. This lining is backed up with a standard 6-in. cupola block lining. All standard precautions for laying silica brick are followed, allowing adequate space for expansion during the heating up process. The truncated cone ends of the furnace can be laid up either with silica brick or rammed silica ganister. Linings will last from 100 to 200 heats when making malleable iron if they have had the proper care through the original and subsequent heating up periods.

10. The furnace can either be operated with a single shell and

spare cone ends, or, as is the case at Indianapolis, with an extra shell and cones, lined and ready for use in the event there is a lining failure in the middle of the week. This spare shell is relined in the horizontal position in a specially designed steel cradle, and is so located that an overhead 30 ton crane can be used to handle either shell.

11. It is the best practice that once the furnace is brought up to the operating temperatures, the lining be maintained at above 1000°F. (538°C.) during shutdown periods of one or two days.

TEST HEATS

12. Shortly after the Brackelsberg furnace was installed at Indianapolis, test heats were made to determine actual melting losses. To accomplish this, all materials making up the heats were carefully weighed and analyzed. Samples were taken throughout the pouring of such a heat, analyzed and an average used. An example of one such heat is as follows:

Composition of Charge	*Weight, lb.*	*Analysis, per cent*		
		Carbon	*Silicon*	*Manganese*
Sprue	8750	2.34	0.86	0.32
Pig	1250	4.09	1.85	0.87

To this charge was also added 25 lb. ferrosilicon, 12 lb. ferro-

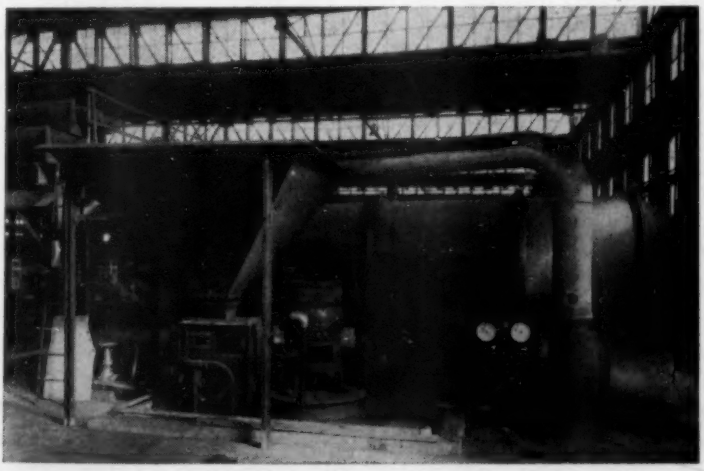

FIG. 4—SHOWING BRACKELSBERG FURNACE WITH PULVERIZING COAL UNIT AND FUEL HOPPER IN FOREGROUND.

manganese and 50 lb. petroleum coke. The charge analysis, including ferroalloys and the coke, was:

	Per Cent
Carbon	2.77
Silicon	1.08
Manganese	0.49

The average analysis of the heat as cast was:

	Per Cent
Carbon	2.53
Silicon	0.93
Manganese	0.34

As can be seen, oxidation losses are low for this type of melting.

SEQUENCE OF OPERATIONS IN MAKING OF A HEAT

The Charge

13. In the making of the first heat of the week, the lining is heated slowly to a temperature of about 2800°F. (1538°C.) before charging. The furnace is then tilted to the charging position, which is at an angle of about 45° to the horizontal axis. The metal charge which has previously been weighed up in 10 long steel pans, each containing a proportionate amount of the charge, is then unloaded into the furnace. The angle of the charging position of the furnace permits the load to slide very readily to the rear of the furnace. If some clogging should occur at the mouth, the furnace can be rotated in this tilted position. This facilitates the movement of the charge to the rear.

Addition of Ferroalloys and Petroleum Coke

14. The ferroalloys and petroleum coke additions, if any, are made after the furnace has been brought down to the horizontal position and the rear, or exit end, of the furnace cleared enough to permit passage of the exhaust gases.

Firing

15. A good wood fire is started in the burner end of the furnace and the burner, primary and secondary pipes which are all mounted as an integral unit and work from a swivel joint are then pushed up against the front end plate of the shell. The

secondary fan, coal pulverizer and coal screw are then started in that order.

Addition of Coal

16. The coal is fed at about a rate of 15 lb. per min., and the amount of secondary air that is used is varied with the degree of preheat. The shell remains in a stationary position for 20 min. after firing.

Rotation of Shell

17. At the end of 20 min., it is rotated one-quarter of a turn in order to bring part of the cold charge to the surface and to work the surface or hot part of the charge to the bottom. This is repeated at intervals of 10 min. Forty-five min. after firing, continuous rotation of the shell is begun.

Taking Preliminary Analysis Sample

18. Final firing adjustments are made at this time, and no further attention is necessary until a sample is taken from the heat for preliminary analysis. The preliminary sample is taken about 30 min. before tapping and is analyzed for carbon, silicon and manganese. If any ferroalloys or petroleum coke additions are necessary, at least 10 min. is allowed for thorough mixing. Since it is impractical to rabble the heat, the rotation of the shell must be depended upon to disperse the ferroalloy or coke additions. These should be distributed as nearly as possible throughout the length of the bath for uniform recovery.

Tapping

19. Tapping is done either through a spout in the front cone or through the side of the shell near the front of the furnace. Because of the fact that the shell can be rotated clockwise or counterclockwise, it is possible to tap out a heat a ladle at a time if need be, without necessitating the use of hold-up bars or plugging.

Slagging

20. No slagging is done until after the heat has been taken out of the furnace. This is then accomplished by tilting the furnace to the charging position again and emptying the slag through the exit end of the furnace into a pit containing a bucket to catch the slag. The slag on top of the metal serves as a protective covering and minimizes the amount of oxidation during heat-

ing up and tapping periods. This slag does not retard heat exchange to any appreciable extent, because metal temperature pick-up is obtained as the hot lining surface passes under the bath. Heat transfer from lining to metal as the furnace rotates also aids in prolonging the refractory life, because no area of lining is exposed to maximum heat for any sustained period.

ADVANTAGES

Uniform Operation

21. When making heats of the same tonnage and analysis specifications, the Brackelsberg furnace can be depended upon for uniform operation, both as to melting time and composition. Definite heat schedules can be and are maintained with proper supervision.

Wide Melting Range

22. Tapping temperatures as high as 3100°F. (1704°C.) can be obtained which makes the furnace adaptable for a wide range of melting.

Speed and Fuel Consumption

23. A 5 ton heat of low carbon malleable iron can be made in 2 hours or less from firing until tapping time. Fuel consumption will average between 350 to 450 lb. per ton of melt.

Efficiency and Economy in Continuous Operation

24. After the first heat of the week, it is unnecessary to preheat the lining, if the heats are made one after another and the furnace is kept operating at least 16 hours a day. Efficiency and economy in the performance of the Brackelsberg furnace hinges on a rather continuous operation.

DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

Co-Chairman: A. M. Fulton, Northern Malleable Iron Co., St. Paul, Minn.

R. W. PARSONS[1]: The speaker has repeatedly called these 5-ton units. I do not see any reason to doubt his word, but the caption under the illustration says 8-ton capacity furnaces. It may be that, while these actually are 8-ton furnaces, they work better on 5 tons. I would like to know about this.

MR. MASON: The furnaces at Indianapolis are 5-ton furnaces, but at our Cleveland plant we have, or did have, three 8-ton furnaces.

CHAIRMAN JOSEPH: Does that mean that you can charge that many tons, 8 tons per furnace?

MR. MASON: Eight tons per heat.

CHAIRMAN JOSEPH: Not 8 tons per hour. You said that it takes about 2 hr. to melt 5 tons.

MR. MASON: Of low carbon malleable, after the first heat.

CHAIRMAN JOSEPH: You mean from 2.00 to 2.10 per cent carbon?

MR. MASON: No, from 2.20 to 2.40 per cent carbon.

DAVID TAMOR[2]: I notice that you use silica brick for your inner lining. What was the reason?

MR. MASON: When we first started we put in some fire clay linings, but we found we had too much joint erosion. I suppose this was due to natural shrinkage, which does not occur in silica brick lining. Consequently, the linings fell out after a few heats.

D. I. DOBSON[3]: You state in the paper that the Brackelsberg furnace melts about 5 tons in 2 hr. and, from the construction of it, it appears to be a rather expensive installation cost for the tons per hour. I wonder if you have any other predominant reasons for adopting that type of a melting medium.

MR. MASON: It is true that, as a production unit, the Brackelsberg furnace does have its limitations, unless you employ a holding furnace in connection with it, but our shop is more or less of a jobbing shop, and we have made regular malleable, low carbon iron and high carbon iron in successive heats. That is, we have a wide variety of jobs in the shop and, since the Brackelsberg is rather adaptable, it has served our purpose very well.

CHAIRMAN JOSEPH: Have you ever tried to use the Brackelsberg as a duplexing unit, where you took molten cupola metal and superheated it?

MR. MASON: No.

CHAIRMAN JOSEPH: Would that seem practical?

MR. MASON: I do not know whether anyone has ever tried it.

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[1] Ohio Brass Co., Mansfield, Ohio.
[2] American Chain Malleable Foundry, York, Pa.
[3] General Malleable Corp., Waukesha, Wis.

MILTON TILLEY[4]: There have been experiments with a combination cupola and Brackelsberg. You can call it cupola, but actually it is a stack melting. The charge runs directly into the furnace, using the fuel through the furnace first, and there is a continuous flow of metal through the furnace. So far, I have not seen any production.

CHAIRMAN JOSEPH: I should think that it would be rather an expensive procedure, unless it would be possible to use the Brackelsberg unit, running the metal out of the front end and into the back end, or something like that.

W. R. JAESCHKE[5]: Referring to Mr. Dobson's question about the advantages of the Brackelsberg, I think he missed the coal consumption figure of 350 to 450 lb. Since 450 lb. is rather high and the 6 to 1 is not uncommon for melting malleable iron in a rotary furnace, this presents another consideration in fuel economy.

A further consideration is the flexibility of the furnace in being able to melt small heats quickly. As Mr. Mason says, they run a very good malleable foundry there. They have small work in the shop which does not require 35018 specifications iron, and they do not try to pour it with a 2.20 per cent carbon metal, but melt higher carbon iron for this work. As a result, there is a very low scrap loss. If they have some heavy work in the shop which requires lower carbon metal, they run a heat at 2.20 per cent carbon, and for their regular malleable they will run 2.50 per cent carbon. In this way, there is a lot of advantage in the flexibility of the unit.

Mr. Tilley mentioned the development of adapting this to duplexing. Actually, what they were working on was a continuous melting furnace, to melt and superheat with the same flame. It was not very successful, and for the past year or so there has been nothing further done with it.

The oxidation losses in the rear end rather resemble the experience that Mr. Forbes mentioned in his divided-air furnace. He lost a little bit too much of the metal alloys in the pre-heating zone before they got down to the bath. I would not say that the issue is entirely dead; it may come up again after the war, when we have more time to work on things of that type, but the idea was to develop a continuous low-carbon melter with the thermal efficiency of a rotary furnace.

H. A. SCHWARTZ[6]: I would like to offer the suggestion that it is not always a bad idea to have small capacity. We have spent considerable time this afternoon, talking about what to do with the heat the last 2 hr. while pouring it. You have so much metal and you are trying to hold it. If you have 5 tons of metal and wish to get it out quickly, that difficulty does not exist.

There is such a thing as concentrating too much upon a large scale unit and a continuous operation, thereby creating difficulties which small units, perhaps, obviate.

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[4] National Malleable and Steel Castings Co., Cleveland, Ohio.
[5] Whiting Corp., Harvey, Ill.
[6] National Malleable and Steel Castings Co., Cleveland, Ohio.

There are analogies to that in the steel business. Our company is going rapidly to small furnaces.

MR. DOBSON: I haven't missed the fuel consumption angle on the Brackelsberg, but I noticed that it was obtained with a rather continuous operation of at least 16 hr. a day. I must confess, I do not know what it takes to keep the furnace up to heat when not melting the iron, but I presume that shutdown periods raise the fuel consumption appreciably.

MR. MASON: That is true. At present we are down two days; we operate five days, and we plug up both ends of the furnace, letting the temperature drop to whatever it will on Saturdays. Then on Sunday we re-heat it with a wood fire, a slow wood fire, or with an automatic coal stoker. When we reach 900 or 1,000°F. with wood or the stoker, we fire it with the pulverizer and get it up to the charging temperature.

Ordinarily, I do not believe we will burn more than 1½ to 2 tons of coal in preheating the shell for the first heat.

R. A. WITSCHEY[7]: I would like to ask what the refractory consumption is per ton of metal melted in the Brackelsberg.

MR. MASON: At present it will approximate $1.00 a ton, but we are making a good bit of steel, which raises the cost quite a bit. Mr. Tilley, would you care to elucidate on your refractory costs in making steel?

MR. TILLEY: It is approximately the same. We have a holding furnace.

MR. MASON: Maybe it would be in order for you to describe the operation.

MR. TILLEY: It is simply two Brackelsberg furnaces, located with a holding furnace in between them, so that the Brackelsbergs can be dumped into the holding furnace, from side to side, as they melt down.

In our 8-ton heats, we also melt down in two hr. It makes no difference what size the furnace is, the melting rate per heat is the same.

The metal in the holding furnace is kept hot by a proper amount of fuel. The reason we use the holding furnace is to furnish a continuous supply on a continuous conveyor. There is practically no loss involved. It is strictly a holding furnace, and no changes are made in the analysis in it. This holding furnace will hold 20 tons when it is full, and we operate about 12 tons as an average, which is about 2 hours of pouring time.

CHAIRMAN JOSEPH: What are the properties of the metal in the Brackelsberg unit, with regard to shrinkage and machineability, and ultimate and yield strengths, compared to the same kind of malleable that is made in the cupola air furnace? Is the shrinkage and cracking worse, or could you tell us some of the properties of it? You people make iron both ways, don't you?

MR. MASON: Yes.

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[7] A. P. Green Firebrick Co., Chicago, Ill.

CHAIRMAN JOSEPH: Is there any comparison you can draw between the two, as to which metal is preferred with regard to losses and properties?

MR. TILLEY: You must understand that we are making graphitic steel in this Brackelsberg, not malleable.

MR. MASON: Ask Mr. Zeunik to answer that; he is our metallurgist.

MR. ZEUNIK: Our properties on Brackelsberg metal, when compared with air furnace metal of similar composition, are about the same. We often work the same pattern on either type of melting without any change in gating or feeding, indicating that shrinkage and hot tears are not any worse. We have less misrun work on the Brackelsbergs, because it is possible to get the metal hotter. Tensile strength, yield point and elongation properties of Brackelsberg metal are about the same as those of air furnace metal. I would not say that they are any better.

MR. WITSCHEY: In lining the furnaces, do you line the barrel of the furnace with silica brick, and with what are the conical ends lined?

MR. MASON: The shell is lined with standard silica brick, either 6-in. or 9-in., and it is our practice, at Indianapolis, to ram up the cones with silica ganister. The Cleveland plant uses a brick in the cones, especially shaped for the purpose.

Melting Cupola Malleable Iron

By H. W. Maack*, Chicago, Ill.

Abstract

When and where a cupola was first used for melting malleable iron is obscure, but it succeeded crucible melting early in the history of the industry.

In the United States about 8 per cent of the total production of malleable iron is melted in cupolas, for direct pouring. In Germany, according to last reports, about 75 per cent is so melted, principally whiteheart malleable iron. Because of its economy, cupola melting is the first step in duplexing and triplexing processes, widely used where continuous pouring is required. About 27 per cent of the total production in the United States is so melted.

Cupola practice details are somewhat different from those for gray cast iron melting, more careful control being necessary to insure best possible uniformity. Cupola charge and operation are such that carbon content is maintained at the desired value, the silicon and carbon in such relation that the castings are free from primary graphite, and the manganese and sulfur in proper ratio. The various factors of mixture control and cupola operation demand constant and unremitting attention.

Cupola melted malleable iron is usually of higher carbon content than other process malleable. This makes it particularly well suited for the manufacture of pipe fittings of thin section, which must be sound to insure tightness under pressure, and easily machinable in large production quantities, giving smooth accurate threads. A large percentage of pipe fittings is galvanized, and cupola malleable is practically non-susceptible to galvanizing embrittlement.

History

1. The date and place of the first successful use of a cupola for the melting of iron in connection with the production of malleable castings seems to be obscure. In Germany it is reported to have been near the end of the nineteenth century[1]. However, it is a

* Chief Chemist and Metallurgist, Crane Co.

1 Superior numbers refer to bibliography at end of paper.

Note: This paper was presented at a session on Malleable Foundry Melting Symposium at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 29, 1943.

matter of some interest that the first recorded evidence of the cupola melting of iron in Europe was in 1722, by the Frenchman Reaumur, who, in the same year, disclosed the malleableizing process; also, that in 1794 the cupola was patented by John Wilkinson in England. At about this time malleable manufacture was practiced in England with considerable success. It seems likely, therefore, that cupola melting of iron for malleableizing might have been started first in France, England, or the United States. With regard to the latter possibility, Seth Boyden, the discoverer of the blackheart process, is reported to have built a "large air furnace" of 1000 lb. capacity in Newark, N.J., in the year 1826, and finished building his first cupola in February, 1832. Hard coal was used as fuel in the cupola melting of malleable iron.

2. Considering cupola melting solely from the metallurgical viewpoint, it seems most likely that European, or whiteheart, malleable iron was the kind first made in this type of furnace. The manganese-sulfur ratio, not early understood, is less critical in whiteheart than in blackheart malleable, and composition control, therefore, is simpler. Castings made of iron which lacked the proper ratio, when annealed, would have properties and fracture more like those expected of whiteheart iron.

3. Like air furnace and open-hearth melting, cupola melting followed crucible melting when the increasing demand for malleable castings and the desire for lower costs dictated a departure from the crucible process. The adaptability of the cupola to fluctuating demands and outputs and its low cost of melting were largely responsible for its adoption, although at some sacrifice of quality as compared with crucible melted iron.

DUPLEXING

4. Because it is the cheapest known method of melting iron, cupola melting is the first step in duplexing processes. The first use of a cupola for melting iron for malleableizing, after subsequent refining in other furnace, is credited to W. G. Kranz of The National Malleable & Steel Castings Co. in 1913-1914[2]. Cupola-electric furnace trials were not successful, but they led to the triplexing patents issued to Kranz. As is well known, cupola-electric furnace duplexing has since been perfected and used.

5. The first successful use of a cupola-air furnace duplexing process is claimed for V.S. Durbin of the Southern Malleable Iron

Co. of East St. Louis, Ill., in 1927[2]. Because it permits lower cost of metal at the spout and continuous pouring, this process is of growing economic importance in the industry.

OUTPUT

6. In the United States, direct cupola melting accounts for only about 8 per cent of the total output of malleable iron. This is used almost solely by the pipe fittings industry. In Germany, in 1936, 87 per cent of the malleable iron foundries were using cupolas to melt about 75 per cent of the total output[1]. From this same source of information, we learn that only 18 per cent of the German output was blackheart malleable, and 16 per cent of the blackheart output was melted in cupolas.

THE CUPOLA

7. A standard cupola is used for melting malleable iron, but certain refinements in operation are necessary as compared with gray iron melting practice. Depth of hearth (distance from sand bottom to tuyeres) can be less than in gray iron melting practice because the iron is tapped from the cupola at about the same rate as it is melted. A single row of tuyeres is preferred. A hearth depth of about 18-in. is common. The sand bottom of rammed molding sand, 9 or 10-in. deep, slopes toward the tap hole in the breast brick, often a two-holed fire clay block obtained from a manufacturer of refractories. The molten iron from the cupola spout is caught in a mixing ladle with teapot spout which is, preferably, large enough to hold at least two iron charges.

8. Front slagging or back slagging can be used. In the latter practice a slag hole about 3-in. below the tuyeres has been found suitable. Blower for cupola blast may be fan or positive pressure type. Blast pressure, or volume, is closely watched and adjusted according to melting rate required by the foundry. Melting capacity can be calculated by the usual formula, i.e., 11 lb. per hour per square inch of cupola cross sectional area at the melting zone.

9. Fire clay cupola blocks and bricks are used for lining the shell. Repairs to the lining at the melting zone, between runs, can be with firebrick, slabs of mica schist, or with refractory sandstone. Ganister mixture can be used to set the brick, or slabs, and fill openings which may develop between them.

COKE

10. By-product coke is considered the best fuel, being less friable than beehive coke. Special low carbon pick-up coke is available, if desired, and is largely used in cupola melting of iron for duplexing. Size of pieces must be proper for the cupola lining diameter and of the best foundry coke characteristics to insure uniform temperature and rate of melting.

11. Proper height of the coke bed is most important for uniform melting and hot iron, and this bed height must be maintained throughout the run. Height of 50-in. above the tuyeres is about right for a cupola operated with 16 to 20 oz. pressure of blast, and higher or lower bed heights for increased or lower pressures, respectively[3].

12. Ratio of iron melted to coke consumed is usually between 5.5 and 7 to 1. This melting efficiency is somewhat lower than is usual for gray cast iron melting. Higher efficiency is possible, but it entails less flexibility in melting rate, or the use of preheated blast.

IRON MIXTURE

13. Besides foundry returns in the form of cleaned sprues, gates and scrap castings, pig iron, steel scrap, spiegel and ferrosilicon make up the metal charge. Malleable iron scrap is also usable when available. Foundry returns may comprise 40 to 50 per cent of the charge. The average carbon content of the metal charge is usually about 2.25 per cent.

14. Manganese and silicon additions to the charge, for obtaining the desired composition in the iron, may conveniently be in the form of briquettes in which the ferro alloys in known amounts are held in Portland cement. Besides their convenience advantage, these briquettes tend to reduce melting losses of silicon and manganese. Spiegel and silvery pig iron are preferable to more concentrated manganese and silicon alloys because they permit closer control of these elements in the malleable iron.

15. The sulfur content of cupola and duplexed malleable iron is usually higher than that of iron melted in air furnaces. Regardless of the melting process, sulfur in blackheart malleable must be neutralized by manganese to have the castings anneal to give a normal blackheart fracture. In cupola iron the general rule for manganese content is $2\frac{1}{2}$ to 3 times the sulfur content[4]. An ex-

cess of manganese above this ratio also tends to prevent thorough annealing to blackheart fracture.

16. The iron ingredients of the charge should be of a size required by the diameter of the cupola lining. Obviously a large diameter cupola can accommodate bigger pieces than a small one. Steel and iron scrap should not be too small or too thin. Small scrap might sift through to the charge below, and thin sections might be oxidized in the upper zones of the cupola. Use of wrought iron scrap is to be avoided because its phosphorus content is too high. Pig iron used is of malleable grade, as indicated by its silicon, manganese and phosphorus content.

FLUX OR SLAG

17. Limestone or dolomite is used as a flux for producing slag. To some extent the size of the pieces depends on the size of the cupola, but stone should not be too small (less than ½-in.) or it will sift through the coke charge, or be blown up the stack. The flux charge is about 15 to 25 per cent of the coke charge in weight, and it is thrown near the center of the latter to avoid attack on the lining. If sprues are not free of sand, or scrap is coated with thick rust, more flux is necessary.

18. Coke for the cupola bed and charge splits, stone for fluxing, and all ingredients of the iron charge should be weighed and the weight recorded on daily cupola log sheets. These can then be summarized and, together with analysis and physical test results, recorded for future reference and operating guidance.

MELTING CONTROL

19. Using a cupola charge of fixed proportions of the selected ingredients, and operating the cupola to melt at a uniform rate, temperature of the molten iron will be quite constant. These factors largely control the carbon content of the iron. Through the use of test sprues, cast and fractured at frequent intervals, the chilling qualities of the iron are watched. The diameter of the test sprues used and the appearance of their fractures—whether clear "white" or having a few or many mottles—determine the suitability of the iron for the castings being poured. Test sprue diameters from 1 to 2-in. are common. The chilling quality of the iron is adjustable by varying its silicon content, through additions of ferrosilicon, to the cupola charge. These methods constitute the well known practice of controlling malleable iron, but there are other telltale

characteristics watched by the experienced melter and used in control. The surface appearance of the iron in a ladle, or from the cupola spout, and the sparking of the iron are also indicative of temperature and composition. An experienced melter anticipates changes and makes compensating charge adjustments beforehand.

20. Temperature of the molten iron also governs its use for sections of different thickness and the distance it can be carried from the cupola without excessive loss of fluidity and likelihood of misrun castings. Normal temperature at the cupola spout is from about 2775 to 2850°F. Uniform temperature and composition require a uniform rate of melting which presumes that the operations of molding and pouring are correlated with cupola operation. A thoroughly mechanized foundry facilitates meeting these conditions.

21. Making blackheart malleable iron castings of good quality requires composition such that the normal annealing treatment will precipitate practically all of the carbon present as temper carbon nodules and, also, such balance of elements that all of the carbon in the white iron castings will be in the combined form. So-called primary graphite, shown by black mottles in the fracture of the white iron, lowers strength and ductility. High carbon and/or high silicon, and slow cooling promote the formation of unwanted primary graphite.

ANNEALING

22. Cupola malleable, normally produced in considerable tonnages, is usually annealed in large batch type furnaces, fired with oil or powdered coal. The total time cycle, which must be effective for the iron most refractory to anneal in the least favorable location in such furnace (the bottom corners), is about 100 hours for a 60-ton capacity furnace. In short cycle furnaces, 48 or 50 hours has been satisfactory.

PROPERTIES

23. An article on a process of melting seems incomplete without mention of the properties of the metal so melted. Therefore, for completeness, the following is given, copied from the 1940 edition of the American Foundrymen's Association *"Cast Metals Handbook."*

CHEMICAL COMPOSITION

24. "The essential difference between cupola and air furnace malleable iron is the higher percentage of carbon in the cupola hard iron. The percentages of manganese and sulfur are also higher but, when kept in proper ratio, neutralize each other and have no appreciable effect upon the physical properties of the iron.

25. "High carbon content gives more fluidity and less shrinkage. Consequently, valves and fittings, which are tight under water and steam pressure, can be made, using smaller gates and feeders than are required when lower carbon malleable iron is used for this purpose. The relatively high yield point gives such product strength with ample factor of safety. High carbon content makes the iron easy to machine, assuring finely finished surfaces and smooth accurate threads which are so essential to the serviceability of malleable pipe fittings.

COMPOSITION AND PROPERTIES OF CUPOLA MALLEABLE IRON

Chemical Composition	*Range*	*Most Probable Value*
Carbon range (white iron), per cent	2.80-3.10	3.00
Silicon, per cent	0.70-1.10	0.85
Manganese, per cent	0.40-0.60	0.50
Phosphorus, per cent	under 0.20	0.10
Sulfur, per cent	0.15-0.25	0.17
Physical Properties		
Specific Gravity	7.10-7.20	—
Shrinkage Allowance (depending on cross-section and method of anneal) in. per ft.	0-0.125	—
Mechanical Properties		
Tensile Strength, lb. per sq. in.	40,000-55,000	45,000
Yield Point in Tension, lb. per sq. in.	30,000-40,000	34,000
Elongation, per cent in 2 in.	5-12	8
Modulus of Elasticity in Tension, lb. per sq. in.	—	27,800,000
Brinell Hardness Number	100-120	110
Izod Impact Value, ft.-lb.	7-9	8
Charpy Impact Value, ft.-lb.	4-6	5

TENSILE PROPERTIES

26. "The higher carbon of cupola malleable iron, as compared with that of most air furnace malleable irons, tends to lower the

tensile strength (40,000 lb. per sq. in. minimum). The yield point in tension is high (30,000 lb. per sq. in. minimum). This comparatively high yield point, together with high carbon, gives cupola malleable iron valuable properties which make it especially suited to the requirements of the malleable iron valve and fittings industry.

EFFECT OF HIGH TEMPERATURE

27. "The effect of temperature upon the physical properties of cupola malleable iron is the same as upon air furnace iron. The critical point is reached at about 1400°F., above which the physical properties of malleable iron are completely changed. As with air furnace iron, strength begins to drop rapidly at about 800°F.

EFFECT OF GALVANIZING

28. "Cupola malleable iron is well suited for galvanizing and a large proportion of this product is so treated. Little or no trouble with galvanizing embrittlement is encountered."

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DISCUSSION

Presiding: Dr. H. A. SCHWARTZ, National Malleable and Steel Casting Co., Cleveland, Ohio.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

F. J. WURSCHER[1]: I would like to ask if the speaker can give an account of his reasons why cupola malleable iron is less susceptible to galvanizing embrittlement than air furnace iron?

MR. MAACK: I cannot recall the reason at the moment, but there is a theory pertaining to it.

RALPH GREENE[2]: I think that falls in line with the phosphorus-silicon ratio, at least that has been our experience over the past twenty years—the minute the phosphorus gets a little high, we suffer galvanizing embrittlement.

M. E. MCKINNEY[3]: I'd like to correct an impression which has been associated with cupola blackheart malleable. The figures advanced are far below those which can be attained with cupola blackheart malleable, without any duplexing whatever. It is possible to obtain a malleable which will give the characteristics of the lower grade—50,000 lb. per sq. in., 10 per cent elongation—consistently and run carbons, not as high as has been stated but at an average of 2.60 per cent, with a variation of 2.40 to 2.80 per cent without any duplexing.

We have run this method consistently for some 12 yr., in France and Germany, without any trouble, and these specifications are not favorable to cupola blackheart because much better results can be achieved. The duplexing people have proved that they can hold their carbons at 2.60 per cent, coming from the cupola.

MR. MAACK: I concur in Mr. McKinney's statements. However, iron with lower carbon content has somewhat different castability and machinability and, of course, greater internal and dimensional shrinkage. All these factors are important in the manufacture of malleable pipe fittings, which must be cast and machined in large production quantities.

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2 Detroit Brass and Malleable Works, Wyandotte, Mich.
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Practical Operating Phases of Melting

By J. H. Lansing*, Cleveland, Ohio

Abstract

A comprehensive treatment of the advantages and disadvantages of different types of furnaces employed for melting, including their respective sizes and constructional features in order to maintain efficient operation at minimum cost. Comparative analyses of the economy effected by the use of various kinds of equipment contribute immeasurably to the value of this article.

1. In dealing with practical operating phases of melting, consideration should be given to the various types of equipment in use. These may be listed as follows:

(a) Air Furnace
(b) Duplex
(c) Open-Hearth
(d) Brackelsberg
(e) Electric

2. In over 90 per cent of malleable iron produced in the United States, air furnace and duplex melting equipment are used. These types, therefore, are entitled to the greatest consideration.

Air Furnace Types

3. Under air furnace types are included the pulverized-fuel-fired furnace, the oil-fired furnace, and the hand-fired furnace. In this case again, approximately 90 per cent of direct-air-furnace-melted malleable is produced in the pulverized-fuel-fired furnace. The hand-fired furnace, largely used in the industry until approximately 20 years ago, had the disadvantage of involving more and harder labor, a rather large fuel consumption and difficulty at times in heating the metal to adequate temperature, resulting in "late heats." Oil-fired-air-furnace melting still has a few enthusiastic advocates who obtain excellent results with it. Generally speaking, however, the greater oxidation, requiring the use of a

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larger percentage of pig iron, has, under normal conditions, made for a slightly higher metal cost, and the oil fuel cost has been somewhat higher than in the case of pulverized fuel.

4. In firing air furnaces with pulverized coal, the early central plants equipped with driers gave quite satisfactory results. In the case of the first individual unit pulverizers, not drier equipped, it was difficult to obtain adequate fuel fineness and, therefore, adequate combustion and temperature, especially with wet or moist coal. However, improvement in unit pulverizers made for better results, and now, with air separation widely used, their operation is quite satisfactory.

5. A list of air furnace charges for various types of air furnaces would be approximately as follows:

	Pig Iron, per cent	*Scrap, per cent*	*Sprue, per cent*
1. Hand-fired furnace	45	5	50
2. Oil-fired furnace	45	5	50
3. Pulverized-fired furnace ...	33	17	50

6. Average fuel consumption per ton of iron melted in the various types of furnaces would approximate:

1. Hand-fired furnace ..... 850 lb.
2. Oil-fired furnace ..... 55 gal.
3. Pulverized-fired furnace .... 650 lb.

Variations from the above will be encountered, depending upon the size of heat, but the figures given are comparable with each other. Among the advantages of direct-air-furnace melting may be included the fact that such equipment is suitable for either large or small foundries, and does not require that a high degree of production be maintained at all times. Also of advantage is the fact that any range of metal may be easily and consistently produced. In the case of this equipment, it is not difficult to obtain carbons in the medium and lower ranges since, during melting, the metal is not in contact with the fuel.

DUPLEXING TYPES

7. Among duplexing types may be included the cupola pulverized-coal-fired air furnace; the cupola oil-fired air furnace; and the cupola electric furnace.

8. The cupola pulverized-coal-fired air furnace is in most general use; the cupola oil-fired air furnace has the advantage of easily keeping the carbon down to a desired point; and the cupola electric furnace method is the type having the largest single continuous installation.

9. Charges are generally made up of approximately 50 per cent sprue, 35 to 45 per cent scrap, and from 5 to 15 per cent of pig iron. To maintain the desired silicon content, at least part of the pig is generally silvery iron.

10. An average fuel consumption may be given as 250 lb. of coke per ton of iron melted for the cupola and some 300 lb. of coal per ton of iron melted for the air furnace, or from 20 to 25 gal. of oil per ton, if the duplexing air furnace is oil-fired.

11. Among the advantages of duplex operation is the fact that continuous metal is provided and, generally, a lower charge, refractory, and labor cost obtains. There is no saving in fuel. Also, control cost is higher, and more difficulty is encountered in producing metal with carbon content of the medium and low range. Duplex operation is the most efficient with large production, and should not be used unless one is assured of a regular minimum melt of at least 50 tons daily.

12. An analysis of charge, cupola forehearth, and duplex air furnace metal may be given as shown in Table 1.

Table 1

METAL ANALYSES THROUGHOUT DUPLEX AIR FURNACE HEAT

	Composition, per cent			
	Silicon	*Manganese*	*Sulphur*	*Total Carbon*
Charge	1.35	0.83	0.085	1.79
Cupola forehearth	1.13	0.48	0.128	2.84
Duplex Air Furnace	1.10	0.44	0.130	2.50

13. In Table 1 may be noted the necessarily high manganese content to take care of the high sulphur.

ELECTRIC MELTING

14. Electric furnace melting has the advantages of some metal cost saving, due to the small amount of pig iron used, and the fact that high temperatures are easily obtainable. Of disadvantage are the high original installation cost and the fuel cost. Fuel consumption is reported as approximately 600 kwh. per ton.

BRACKELSBERG

15. Rotary furnace melting, of the Brackelsberg type, involves the use of a charge of approximately 10 per cent pig, 40 per cent scrap, and 50 per cent sprue. Fuel consumption is from 400 to 500 lb. per ton of metal melted, and good control of metal and any desired composition are obtained. There is some variation in experience with the acid refractories, lining life being reported as from 100 to 250 heats.

16. An advantage of Brackelsberg furnace use is that large percentages of borings or turnings may be used without briquetting. Actual weight checks have indicated a nearly complete recovery of metal, and the use of two or three units will furnish continuous metal. The size of heats is, of course, small, being from 4 to 6 tons. Of disadvantage is the necessity of operating at least two shifts to get maximum economy, although the Brackelsberg may be used as original melting equipment in conjunction with a "holding" air furnace.

OPEN-HEARTH

17. Fuel costs of open-hearth malleable melting are generally higher than in the case of the air furnace, but refractory costs are lower. Of advantage is the fact that the open-hearth is an excellent equipment for low carbon metal production. Of disadvantage is the original high installation cost.

AIR FURNACE OPERATION

Furnace Size and Construction

18. In connection with air furnace construction, it is of interest to consider factors which determine furnace size. Some years ago, the distance from which molders could reasonably carry iron in hand ladles and pour off their floors was an important consideration. With this was tied up the matter of class of work, that is, whether light or heavy, the consideration of whether one or two heats were to be poured from each furnace daily, and the foundry layout.

19. In the case of a foundry largely producing light work, such as harness snaps, furnaces were generally constructed for the production of approximately 15 tons. Such foundries generally operated on the basis of a single heat per day and were rather typical of plants located in the Eastern section of the country. In the case of the average plant located farther West, many foundries also melted about 15 tons per heat but ran two heats

daily. This made it possible to provide sufficient metal for the heavier class of work without removing the molders farther from the furnace than in the case of the light casting foundry first mentioned. Generally the two-heat plants ran longer hours daily, this allowing time for the melting of the second heat.

20. Prior to the use of pulverized fuel, some large furnaces were in use, but the satisfactory application of pulverized fuel made for much more extensive use of the 25-ton furnace. Several factors contributed to this. First, when pulverized coal firing was applied, the former fire box of each furnace was filled in and the hearth length thus extended by some six ft. Also, when unit pulverizers were used, two units could be employed rather than three, for the melting of 45 tons daily, if heats of 22 to 23 tons were run rather than of the 15-ton size. Moreover, pulverized fuel use made for more rapid melting and enabled the two-heat plants to melt the two heats daily even with a size of some 22 tons.

21. With the use of pulverized coal, higher metal temperatures were attained and increased use of buggy and track ladles was developed to convey the metal to the molders' floor. As transfer ladle use increased, so did the size of furnace and heat in many instances, with the use of insulated ladles, for metal transfer, aiding further.

22. Another factor making for the use of fewer but larger furnaces was the development of mechanical charging equipment, as one crane would thus do the job of charging for a 30-ton furnace instead of needing two cranes for two furnaces of 15-ton capacity. Increased production per unit of floor space also encouraged the use of large furnaces, some melting 60 or more tons per heat being in use.

23. Relative details of furnace construction do not vary greatly in furnaces of different sizes, all dimensions of the larger ones being increased in somewhat general proportion. An exception to this may be furnace width, which is limited by reasonable bung length. Depth of bath, also, is not generally increased in direct proportion. In the case of rapid melting of large heats, larger stacks are, of course, required.

24. Probably the factor requiring the greatest change with relation to large heats is the furnace bottom. In the case of heats running up to 20 or 25 tons, silica sand bottoms give excellent satisfaction, but when considerably larger heats are run, brick bottoms are generally required.

Construction Details

25. Side wall height should be governed by the volume of the charge and for most efficient melting should be decreased when smaller heats are run. A wall thickness of at least 13½-in. is generally found to be desirable. The furnace bottom should slope sufficiently to adequately drain the furnace, the degree of slope depending on how often the bottom is to be replaced. For example, when a new sand bottom is installed each week, it is always cleaner at the end of its run, and, therefore, requires less slope than in the case of a bottom which is required to serve for two weeks. Advantage should always be taken of space in the front part of the furnace, as melting and heating are easily accomplished in this zone. A steep slope from the front wall to the tap holes is, therefore, undesirable and makes for increased fuel consumption. A fall in height of 2 to 2½-in. from the front wall to the "tap holes" and of 1 to 1½-in. from the rear bridge to the tap holes is generally found to be adequate.

26. Rear bridge height is important, as a rear bridge which is high above the iron line prevents the flame from adequately striking the bath. It also makes for a higher roof which prevents effective use of its reflected heat. Rear bridge height may safely be determined by skim door height. The latter should be a split brick thickness 1¼-in., above the molten metal line, and the rear bridge height a brick thickness, 2½-in., above the skim door height. In this way, one is assured that the rear bridge height is not too great and yet that no molten metal will go over it, as the first warning would come at the skim door if too much metal has been charged. It is necessary to maintain rear bridge height by adding a course of split brick when the top of the bridge has been partly burned away.

27. Beyond the rear bridge, or at the base of the stack, there should be an adjustable opening to reduce flame temperature, or to set up a back pressure by reducing the exhaust draft. Stack height has a direct relationship to procurable draft. (In this connection, the necessity of high stacks might be mentioned, some 100 ft. or higher, on the old natural draft furnaces.) It is also important that stack diameter be adequate, to prevent rapid burning away of the stack lining. Such diameter should be at least 4 ft. An early handicap to conversion from hand-fired to pulverized fuel use often was found in too small a diameter of stack. The early burning out of such stacks generally resulted in their replacement

by larger ones or by a reduction in thickness of stack lining, thereby increasing the diameter.

28. Considerable variance in practice may be noted with regard to the height at which the pulverized fuel burners enter the furnace. The burners, two in number, are often advantageously located at a height of but 4-in. above the level of the back bridge in a 25-ton furnace. This places them approximately 7-in. above the iron line in the front of the furnace, or with a 12-in. depth of bath, some 19-in. above the tap hole level. In other cases, however, entrance is often preferred at a height at least double that of the foregoing. In all cases, the burners are slanted downward rather than entering the furnace in an exactly horizontal position. It is customary to arrange the piping from the pulverizer so that at some time in its course, the pulverized fuel will travel up, rather than down at all times, thus effecting a better mixing and distribution of the fuel in the air stream.

Furnace Bottoms

29. A good furnace bottom generally makes for faster melting and higher temperature metal. Many attempts have been made over a period of years to increase bottom life. In the case of the standard silica sand bottom, it is generally believed to be a false economy to try to run the bottom for more than one week. By the end of the week the bottom has accumulated a certain amount of slag, often some small slabs of iron in various locations, and the general condition of the furnace bottom does not improve when reheated, following cooling to a much lower temperature than any to which it has dropped during the active working period. There is a greater tendency for cracking and for "coming up" of pieces of the bottom. With the use of a quite pure sand in a 25-ton furnace, it is usually possible to remove a bottom in 4 man-hours or less and to install a new one in not more than 2 man-hours. One and one-half tons of new sand are generally adequate for this purpose. This cost is not high when compared to additional fuel and labor cost and higher foundry scrap when a bottom is used too long.

30. A reasonably pure sand is favored for various reasons. In the case of a sand of lower silica content, fusion is to a greater depth and there is increased probability of substantial cracking of the bottom. The sections of bottom which then rise to the surface are much thicker, thus leaving heavier slabs of iron in their place at the end of the heat. Also less sand is required when the

purer, shallow fusion sand is used, with much less labor being involved in bottom removal.

31. Brick bottoms have had strong advocates at times, but they finally found their field to be that of duplex operation, or in direct-fired air furnaces in which heats in excess of approximately 30 tons are melted. In the case of duplexing operation, furnace linings last longer. Consequently, the necessity of opening the furnace for repair at the end of a week, except with two-shift operation, does not generally exist. It is, therefore, desirable to have a bottom which will last several weeks. Also, in the case of the melting of heats substantially in excess of 30 tons in size, due probably to the increased time per "heat" and increased heat penetration, there is often a tendency for sand bottoms to "come up" thus making brick bottoms preferable for big heats.

Table 2

BRICK BOTTOM STATISTICS

Plant Designation	*Size Heats or Daily Melt*	*Tons Melt per Bottom*	*Thickness of Bottom*	*Type Brick Used*
		(Air Furnace Melting)		
A	31	2000	4½"	Regular Firebrick
B	45	3600	9"	Bottom Brick
C	62	5000	9"	" "
D	65	6500	9"	" "
E	4-20 T. Heats	400	9"	" "
Average	57	3500	—	—
		(Duplex Melting)		
F	23	1860	9"	Bottom Brick
G	45	2000	9"	" "
H	50	3500	9"	" "
I	75	1800	9"	" "
J	80	2020	9"	" "
K	80	3500	9"	" "
L	135	3420	9"	" "
M	160	5000	9"	" "
Average	81	2888	—	—

32. Generally there is not a great difference between sand and brick in bottom cost per ton of iron melted. The brick is more expensive, costs more to install and involves the use of somewhat more fuel in heating up the furnace each day. However, its advantage is longer life, freedom from possible silicon pick-up, and generally the saving of overtime for weekly bottom installation, more important now than in the past. As stated, brick bottoms generally are found to effect an economy only in the case of very large heats

or for duplex operation. This fact is substantiated by a table prepared by the writer for the Malleable Sub-Committee of the Joint Committee on Foundry Refractories. It shows service obtained from bottoms in use in a number of foundries running relatively large heats, or duplexing. All other foundries surveyed at the time ran smaller heats and used sand bottoms. Figures on the brick bottom use in both air furnace and duplex melting are shown in Table 2.

33. Comparative figures covering side wall and bung brick consumption may also be of interest. The basis is that of 9-in. equivalent consumption per ton of iron melted. In the comparison of 32 plants, the lowest brick consumption was with two-heat daily operation, even with relatively small heats, 15 tons being the average figure. Brick consumption of duplexing plants was slightly higher, and that of the single heat plants above that of the duplexing units. Table 3 shows this.

Table 3

SIDE WALL AND BUNG BRICK CONSUMPTION*

Basis: 9-in. equivalent per ton of iron melted

Number of Companies	*Heats Run Daily*	*Average Size Heats*	*Side Wall and Bung Consumption*
10	2	15 tons	9
15	1	37 tons	10.5
7	Duplex	81 tons daily	9.5

34. In the general construction of the furnace, working doors and openings should be at a minimum. Tap spouts should be high enough to permit the use of buggy or track ladles. Deep, rather than shallow, spouts should be used as less metal surface is thus exposed to air and cooling. Adequate "pour-back" openings should be provided.

Type of Charge

35. The generally accepted and satisfactory practice is to place the sprue, which is approximately 50 per cent of the charge, on the furnace bottom, the scrap close to the front bridge wall, and to distribute the pig iron over the top of the two first charged materials. A certain amount of sand adheres to the sprue, but is not

* In the above comparison, types of coal were recorded, but no direct relationship appeared to exist between brick consumption and the use of either high or low volatile coal. The one company, reporting the use of oil in air furnace melting, melted two heats daily and had a low brick consumption of 6.5 brick per ton of iron melted.

ordinarily found to be extremely objectionable. Some plants have tumbled sprue in the past, but it generally has been found that the expense of this operation is not justified. It is a worth-while precaution, however, to make certain that sprue, to which large amounts of sand are adhering, is not thrown directly into a charging bucket. Especially in the case of large buckets, this sand may develop to be a substantial amount and cause difficulty in properly draining the furnace by adhering to the bottom in certain locations. In placing the charge in the furnace, when the melting of especially small annealed or hard iron scrap castings is involved, such a part of the charge should not be placed directly on the bottom, but rather on top of other material which will better permit penetration of heat to the furnace bottom and through the entire charge.

36. In general, malleable iron scrap has always been most desirable from the standpoint of the malleable melter, and railroad malleable scrap has been considered as the most desirable grade. This has been due, in part, to its heavier sections, and to the fact that it comes in larger pieces, making for easier melting and handling unless a magnet is employed. Agricultural malleable scrap has been considered somewhat less desirable in the past, due to lighter sections, smaller pieces, and the fact that it is often much older scrap with an increased amount of rust.

37. In the case of steel scrap, malleable foundrymen have long favored the use of short rail sections and angle bars. This is accounted for by their uniformity of analysis, excellent weight per piece, and ease of handling.

38. Changed conditions in the present emergency have necessitated the use of melting materials seldom used by malleable foundrymen in the past. Practice has been adjusted somewhat to the use of different materials, but the necessity of guarding against scrap containing chromium or other alloys, which may make for the production of inferior malleable iron castings, should be em-

Table 4

AVERAGE ANALYSES OF FOUR CLASSES OF MALLEABLE SCRAP

	Composition, per cent						
Description	*Carbon*	*Silicon*	*Manganese*	*Phosphorus*	*Sulphur*	*Chromium*	*Nickel*
Railroad Malleable	2.10	0.85	0.27	0.165	0.090	—	—
Agricultural Malleable .	2.25	0.75	0.27	0.170	0.090	—	—
Steel Rails	0.55	0.16	0.75	0.050	0.050	—	—
Bundled Steel	0.18	0.18	0.38	0.040	0.040	—	—

phasized. In general, the use of gears, die blocks, springs, or any parts to which alloys may regularly be added, should be avoided.

39. Average analysis figures of four largely used scrap classifications, as reported by a group of users in the Malleable Founders' Society, is shown in Table 4.

40. In connection with the use of scrap for melting, question is often raised as to the amount of metal which may be lost, due to rust on the scrap. This is an item deserving attention when there is but a small differential between the price of scrap and pig iron. In air furnace melting it is possible, by a slight change in melting operations, to use more or less scrap. To afford definite and representative figures, we at one time asked several malleable producers to weigh, clean, and reweigh, several hundred pounds of average, typical, purchased malleable iron scrap from their yards. Results are given in Table 5.

Table 5

RESULTS OF CLEANING MALLEABLE SCRAP

Type Material	*Cleaning Method*	*Original Weight, lb.*	*Weight after Cleaning, lb.*	*Loss in Cleaning*	
				Weight, lb.	*Per Cent*
Railroad Malleable	Tumbling Bbl.	3,522	3,480	42	1.2
Misc. Malleable	Tumbling Bbl.	1,344	1,317	27	2.0
Railroad Malleable	Wheelabrator	817	803	14	1.7
Misc. Malleable	Wheelabrator	500	481	19	3.8
Totals		6,183	6,081	102	1.65

41. The foregoing results, as indicated, give an average loss on cleaning of 1.65 per cent. This is somewhat less than might be anticipated by the average foundryman, judging from numerous expressions on the subject. There is nothing to indicate, however, that the 1-2/3 per cent loss should not be taken as typical of what may be expected of good quality malleable scrap.

Type Fuel

42. Generally, there is no economy in the use of cheap coal for air furnace melting. The B.t.u. content should be high, the sulphur preferably under 0.80 per cent, ash under 6 per cent, and moisture under 3 per cent. The use of relatively low volatile coal is usually favored; that is, a volatile of approximately 20 per cent as opposed to one of between 30 and 35 per cent. Care should be exercised, however, when changing from the use of high to low

volatile fuel, as the lower volatile material ordinarily makes for higher furnace temperatures, and may result in rapid melting of refractories, unless proper precautions are taken. Grinding to a fineness of 80 per cent through a 200 mesh is desirable, since coarse coal makes for slower melting, increased fuel consumption, and greater carbon and sulphur pick-up.

Melting

43. It is generally considered undesirable to try to attain the highest possible temperature in the shortest possible time when starting to melt. The result may be a melting of the top material which will freeze when coming into contact with the lower components of the charge, due to the fact that the latter have not yet been thoroughly heated. It is better practice, therefore, to run with a somewhat lower pulverizer setting during the first three-quarters of an hour, so that the charge may be thoroughly heated throughout before melting starts. This should effect a time saving in the melting of the entire heat.

44. In connection with rabbling and skimming, there are two schools of thought, one being that the heat should be "worked" at the earliest possible moment; that is, bars and hooks inserted for the purpose of loosening up unmelted portions of the charge and moving them into pools of molten metal. In connection with this same practice, the melter generally starts to skim as soon as it is possible to remove some of the slag, in the thought that general melting will thus progress more rapidly. On the other hand, a considerable number of melters do not find it necessary or desirable to work the charge, and defer skimming until the entire charge is molten and at a fairly high temperature. Good results seem to be obtained by various users of each type of practice.

Testing

45. After the heat has been skimmed, a test sprue, some 7 or 8-in. long and approximately 2-in. in diameter, is generally poured from metal obtained by inserting a small spoon ladle in the furnace test door. The cooling of the test sprue is important, in order that its fracture may properly indicate the condition of the metal. It is desirable to leave the sprue in the sand for 5 min. and 5 min. in the air before cooling in water. A rapid cooling soon after pouring the sprue will result in trapping the carbon in the combined form, rather than permitting certain amounts of it to be thrown out in the form of primary graphite. The melter thus will be misled

as to the condition of the heat. Generally, a preliminary analysis is taken but, whether or not this is done, it is advisable to pour test sprues as well, to have an indication as to the possibility of having primary graphite in heavy section castings. If no preliminary analysis is taken, a satisfactory estimate of the analysis of the heat may be made, based on experience with earlier heats of the same furnace, a knowledge of the charge composition, the experience of the heat in melting, and an examination of the test sprues and of a test ladle of molten metal.

46. In melting, the greatest loss in silicon and manganese is effected during the melting-down period, and the greatest loss in carbon during the final heating-up period. These facts afford the melter a guide as to what to expect when his heat has been slow in melting; that is, probably a resultant lower silicon and manganese content than usual. In a similar manner, if the heat has been slow to attain its final temperature, lower than usual carbon content may be anticipated. These items were referred to above as, "experience of the heat in melting."

47. When it is necessary to reduce silicon or carbon content or both, steel or ore may be added. Following such addition, it is desirable to again skim the heat. When elements are low, ferrosilicon, ferromanganese, or petroleum coke may be added as indicated. In the case of any additions, use of a green pole aids in mixing, and it is desirable that approximately 20 min. be allowed to elapse before the heat is tapped. When petroleum coke is added, the blast should be reduced to prevent a rapid burning, or blowing into the stack, of the coke.

Tapping

48. The tap hole may be closed originally with a core or with ground brick, in which case it may be opened easily by use of a small pointed bar heated by dipping into the furnace bath. If iron has penetrated into the tap hole and tapping is difficult, it may be cut through and the heat tapped by use of an oxygen lance.

49. When it is necessary to plug the hole, due to insufficient ladles being available to take the metal away, a bar may be inserted, a clay and ground brick plug used, or the pointed end of a wooden pole inserted for temporary holding. In view of the possibility of the hole becoming substantially enlarged, it is a desirable precaution to have a large plug of approximately three in. in diameter always available for use in emergency. Although use of the plug may

not be required for weeks, it is well to prepare one each day, as at some time it will possibly result in preventing the escape of a substantial portion of a heat. When the last iron is drained from the furnace, it is generally desirable to plug the tap hole with a core.

DUPLEX OPERATION

50. In connection with the cupola and its operation, it is important that metal of as low carbon content as possible issue from the cupola spout. To that end, a large percentage of steel scrap should be included in the charge and a type of coke, from which carbon absorption is at a minimum, employed. Also, an aid in this connection is the use of a front slagging spout with its accompanying shallow cupola well. The decreased time during which the molten metal is in the cupola affords less opportunity for increased carbon pick-up.

51. In the air furnace, used in duplexing, the factors of importance in effecting reduction of carbon content are hearth area and time in the furnace. Increased hearth area naturally involves decreased depth of bath and a greater opportunity for carbon reduction. Time, the other factor, is also important as carbon reduction of metal, which is in the air furnace for only ½ hour, will naturally be much less than that of metal which remains for three or four times that period or even longer. As pointed out earlier, duplexing is only economical when a substantial daily tonnage is regularly required, and it involves the use of a more complete metal handling system than in the case of direct-air furnace melt in two or more furnaces which may be located closer to the points at which the metal is required. As indicated, with duplex operation, especially conveyor production, it is generally easier to run with a somewhat higher carbon content than that which produces the highest physical properties. There are exceptions to this, however, and a number of plants which are duplexing, produce metal to the 35018 or grade "A" specification.

52. In conclusion, it may be said that both direct-air furnace melting and duplex melting have their proper places in the field of malleable iron production.

Malleable Foundry Refractory Practice

By C. A. Brashares*, Pittsburgh, Pa.

Abstract

The refractories used in the cupola, air furnace, acid electric furnace and open-hearth furnace as employed in the production of malleable iron are discussed. The special application of silica brick in cupola linings is presented. Reference is made to the use of high-alumina brick containing crystalline alumina in certain sections of air furnace linings. Refractory practice for the auxiliary equipment such as forehearths, ladles and annealing ovens is also included.

1. On considering the many types of malleable castings produced, the wide range of plant practices and the varying capacity demands, it will be understandable that the present subject covers a broad field.

2. In this article, it is my purpose to discuss the use of refractories in connection with various processes employed in the production of malleable iron as follows:

(1) Cupola—air furnace (duplexing)
(2) Air furnace (cold charge)
(3) Cupola—acid electric furnace (duplexing)
(4) Rotary or Brackelsburg furnace
(5) Acid open-hearth furnace

Cupola Refractories

3. As used in either of the duplexing processes, the cupola provides the means for the initial melting of the metal.

4. While the refractory requirements of the cupola may be divided into several classes, depending upon the section to be lined and the attendant service conditions, these needs generally are met very satisfactorily by high heat duty fireclay brick manutured by the extrusion or "stiff mud" process.

* Harbison-Walker Refractories Co.

Note: This paper was presented at a Session of Malleable Foundry Melting Symposium at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

Upper Section

5. Such brick, especially when made by the de-aired extrusion process, have the properties of great physical strength, high density and low porosity. Accordingly, in the upper section of the cupola lining, where the refractories are subjected to the mechanical abrasion and impact of the charge, the high strength provides the necessary resistance to wear.

Melting Zone

6. In the melting zone, abrasion may also be a factor, but here resistance to corrosion and erosion by the slag and metal becomes of greater importance. The refractoriness of high heat duty fireclay brick is usually adequate for the service.

Well

7. In the well of the cupola the refractory lining is called upon to resist high temperature and the penetration of slag and metal, and the properties of extruded high heat duty fireclay brick, namely, high refractoriness and density, fit them for these conditions.

Maintenance

8. Proper maintenance of refractory linings in cupolas cannot be too strongly emphasized. Care in chipping away slag and slagged areas and in the installation of patches is an insurance against costly lining failures.

High Operating Temperatures

9. With the trend toward higher operating temperatures, resulting from the scrap situation and production requirements, some operators have found the application of super-duty fireclay brick in the melting zone to be economical. The properties of super-duty fireclay brick which are of prime importance for this service are their higher refractoriness and lower porosity and their stability in the high temperature range. By way of illustration, high heat duty fireclay brick have a P.C.E.* within the range of cone 31 to cone 32½, equivalent to a temperature range of 3056 to 3131°F. Super-duty fireclay brick have a P.C.E. within the range of cone 33 to cone 34, equivalent to a temperature range of 3173 to 3200°F.

* Pyrometric Cone Equivalent.

While this increase in refractoriness may seem very marginal, nevertheless, where the refractory is used at temperatures approximating its melting point, such an advantage in refractoriness may be exceedingly important.

10. The porosity of some brands of super-duty fireclay brick is as low as 12 to 14 per cent, as compared to 14 to 22 per cent for high heat duty fireclay brick. The excellent volume stability of super-duty fireclay brick at high temperatures becomes important as operating temperatures approach the point at which appreciable shrinkage might take place in high heat duty fireclay brick. However, it should be stated that while super-duty fireclay brick have proved economical in cupola practice under conditions of especial severity, their use has not been demonstrated to be economical for cupola practice in general.

Silica Brick

11. For many years silica brick have been used, to a limited extent, for cupola linings and, as the severity of conditions is increased at the present time due to such factors as charges of higher steel content, longer melting periods, etc., the use of silica brick is receiving more attention. In their application it is important that full consideration be given to the inherent properties of this

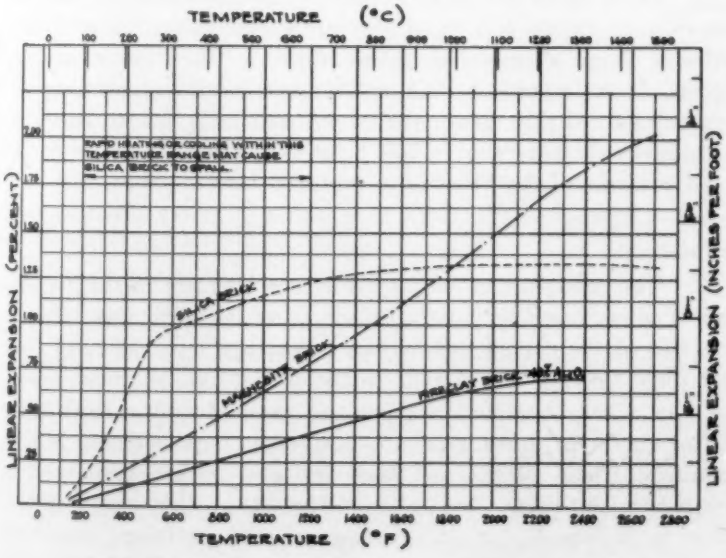


FIG. 1—REVERSIBLE THERMAL EXPANSION OF REFRACTORY BRICK.

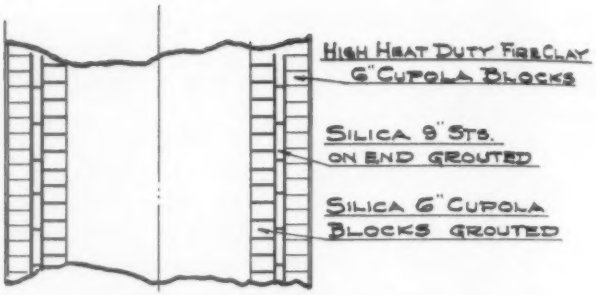


FIG. 2—A METHOD FOR INSTALLING SILICA BRICK LINING IN A CUPOLA.

refractory. At usual furnace temperatures silica brick expand approximately twice as much as high heat duty fireclay brick, and provision must be made for this expansion (Fig. 1). Another property worthy of careful attention is their exceptional strength at high temperatures. Silica brick remain strong at temperatures as much as 500°F. above those at which high heat duty fireclay brick begin to soften under load. This latter property is particularly important in calculating the allowance for expansion, since silica brick do not soften sufficiently to give flexibility to the lining at the usual furnace operating temperatures.

12. Silica brick are susceptible to thermal shock in the low temperature range and must, therefore, be heated slowly, particularly from atmospheric temperature to 1200°F. or slightly higher. It is important that equilibrium conditions of temperature be attained throughout the brickwork since, with an indicated furnace temperature above 1200°F., it is possible that only the exposed surfaces of the brick have reached this temperature.

Installation

13. The procedure, as employed by one operator in the installation of silica brick in cupola linings, may be of interest. In the reservoir of the cupola this operator installs a 6-in. lining of high heat duty fireclay blocks next to the shell. Against these, standard 9-in. silica brick are laid flat and grouted with a thick layer of fire clay. An inner course of 6-in. silica cupola blocks is then installed. These blocks are laid dry and rather loosely, then grouted with silica fire clay (Fig. 2). This same procedure is followed for the lining of the melting zone and for the section extending 16 to 24-in. above it. While no defi-

nite provision is made for expansion, the looseness of the silica brick lining, as laid, has been found to adequately compensate. After the lining is completed it is thoroughly dried by means of a gas burner for a period of 24 to 90 hr., depending entirely upon the length of service secured from a duplicate unit.

Lining Life

14. With silica brick linings so installed, service life of 60 to 72 hr. has been reported with charges of 90 to 100 per cent steel scrap. With charges of lower proportions of steel scrap, this service has been longer. With charges of 65 to 75 per cent steel scrap, campaigns of from 72 to 90 hr. have been reported.

Arch Brick

15. Linings of 6-in. silica cupola blocks have worked satisfactorily as the interior lining. However, in some plants, the arch-type lining has been used to advantage. This merely means that arch brick are substituted for the conventional cupola block. A size well adapted to this construction is the 13½ x 6 x 3-in. arch brick. Theoretically, the advantage of such a size for silica brick is due to the greater number of joints around the circumference. This provides somewhat greater flexibility to the lining and, with a material such as silica, this is an advantage in minimizing spalling resulting from thermal shock. While there are a greater number of joints circumferentially with the arch-type brick, there are fewer joints vertically as compared with the conventional lining using cupola block sizes. In the event that some expansion provision is not made by laying the brick loosely, or if there is no cushioning effect of a mortar joint, it is necessary to provide definite and well distributed expansion joints.

Magnesite Brick

16. Recently, magnesite brick have been employed for cupola linings, particularly in the melting zones. While chemically-bonded magnesite brick have been used, related experiences have demonstrated the superiority of hard-burned magnesite brick where resistance to metal wash is essential. Although this application of magnesite brick has not proceeded beyond the experimental stage, there seems to be some promise for basic brick under particular conditions of operation and slagging practice.

AIR FURNACE REFRACTORIES

Furnace Bottoms

17. Sand bottoms in air furnaces have been used for many years and are still favored in some plants, particularly for furnaces operated on cold charge. Brick bottoms are generally preferred for furnaces used in the duplexing process, and also for many of the furnaces which are cold charged.

18. The treatment which brick bottoms must resist requires that the brick used be stable in volume at extremely high temperatures, chemically resistant to the metal and slag and of as low porosity as possible to minimize penetration with the attendant increased erosion.

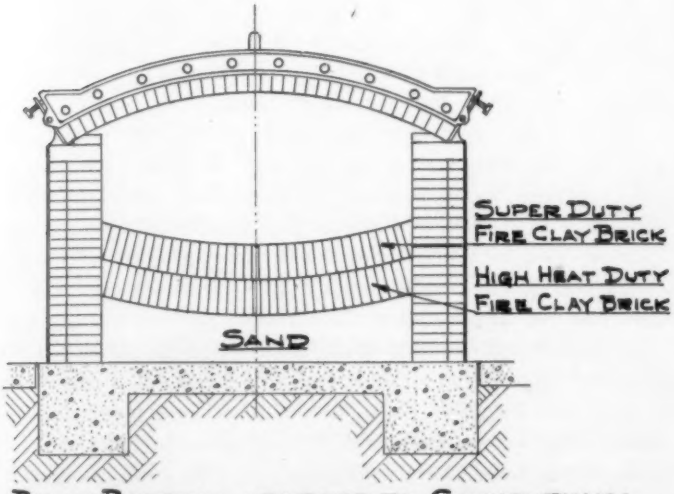
19. Refractories of both the super-duty fire clay and 60 per cent alumina types have been used for brick bottoms. Design and construction of the bottoms vary widely from plant to plant; on duplexing operation, however, the inverted arch is usually preferred (Fig. 3). For cold charging, some operators prefer bottoms slightly arched or crowned, in order to better resist the impact of the charge. Relatively few of these bottoms are now used. In furnaces of the ventilated bottom type, usually it is the practice to install a 9-in. sub-bottom of high heat duty fireclay brick, with super-duty or high-alumina brick above forming the bottom proper or hearth. With the furnace set directly upon the floor, a sub-bottom may be employed to advantage, although some operators prefer placing the main bottom directly on sand.

20. In any event, it is extremely important that the brick bottom be tight, and the usual practice calls for driving the final brick in a given row in order to insure a tight construction. Usually no allowance is made for expansion across the width of the furnace. Longitudinal expansion is provided by a space filled with sand next to the front wall and another similar space next to the bridge wall. The brick are laid with a thin, dipped joint of a good, high-temperature cement, or a very refractory mortar mixture.

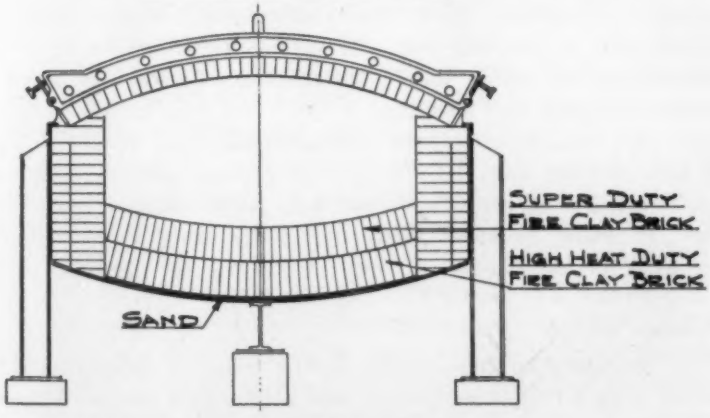
Tap-out Section

21. In the tap-out section of a furnace, of the inverted arch bottom type, considerable cutting usually is required in order to insure proper contour and thorough drainage. The use of a variety of the standard sizes will often minimize cutting. For the unavoidable trimming, some of the recently developed brick saws have been found of material assistance in decreasing the installation cost as well as in securing a very tight bottom.

22. Considering the splendid performance of silica brick in such applications as the rotary melting furnace and of silica refractories in other types of iron and steel furnaces where high temperatures are employed, it seems very likely that they would give good service life in the bottom of an air furnace. However, should silica be promising in this application, it would be in such



BRICK BOTTOM ADAPTED TO CONVENTIONAL FURNACE BOTTOM



VENTILATED BOTTOM

FIG. 3—CONVENTIONAL AND VENTILATED FURNACE BOTTOMS.

furnaces as are on relatively continuous operation, or perhaps where some provision could be made to keep the bottom heated above the critical range for silica. Related trials, so far as known, have been relatively few, and any application of silica for this service would necessarily be entirely experimental.

Side Walls

23. In the majority of air furnaces, high heat duty fireclay brick made by the extrusion process are used for side wall construction. It is important that these brick have high refractoriness, low porosity and high mechanical strength.

24. While super-duty fireclay brick have been employed in side wall service, their use is not general. It seems probable that the most serviceable application of super-duty fireclay brick in side walls will be for those sections where unusually severe conditions prevail. Toward the front of the furnace, where the upper side walls may be exposed to unusual flame impingement and high temperatures, the additional refractoriness offered by super-duty brick may prove sufficient to make their use economical. In some furnaces, the application of high-alumina brick, such as those of the 60 per cent alumina class, in such sections may also prove economical. One successful use of high-alumina refractories in an air furnace has been the employment of two courses of special 60 per cent alumina brick at the slag line. In this refractory, the alumina is primarily in the form of corundum, that is to say, crystalline alumina. Where previously severe erosion had been experienced at the slag line, the special high-alumina brick has so retarded the action that a better balanced side wall life and overall economy have resulted.

25. In some furnaces, the tap-out blocks have been furnished in high-alumina material. They have proved advantageous from the standpoint of better operation and lower cost per ton of output. In many furnaces air-rammed super-duty fireclay blocks are used for the tap-outs.

Furnace Bungs

26. Possibly no requirement of the foundry industry has received more attention and study than air furnace bungs. Although some extruded and some handmade brick are used, special high heat duty fireclay brick manufactured by the power press process are used to the greatest extent for this requirement.

27. In order to meet the conditions imposed upon them, bung brick must be extremely refractory and resistant to thermal spalling. A careful selection of fire clays is made to secure high refractoriness, and the grind is controlled in order to secure a gradation of particle sizes which will contribute to maximum spalling resistance.

28. With the number of variables to be considered, the proper evaluation of various brands in bung service presents a rather involved procedure, but with proper attention given to such details as location, handling of bungs and variable furnace output, a valuable and indicative record can be assembled.

ROTARY FURNACE REFRACTORIES

29. The experience with various refractory linings for the rotary or Brackelsberg furnace furnishes some interesting information relating to the suitability of refractories for contact with iron at high temperatures. Initially, for example, consideration was given to super-duty fireclay brick linings, both the super-duty brick and the extra-hard-burned super-duty brick being tried. While these had demonstrated their suitability for air furnace bottoms, they did not give satisfactory life in the rotary furnace.

30. Silica brick linings were next tried and found to give considerably longer life, with the result that they were generally adopted for the requirement. Because of their relatively high thermal conductivity, silica brick, when used for the inner lining, are backed with fireclay brick in order to protect the shell from excessively high temperatures. In the installation of the fireclay brick backing, the brick usually are laid tightly, and the expansion of the steel shell is relied upon to provide the necessary allowance for expansion. Definite provision for expansion should be made in laying the silica brick inner lining. This is accomplished by inserting strips of paper or cardboard between the brick, both in the longitudinal and the circumferential joints. It is good practice to distribute the expansion spaces.

31. As in most furnaces, refractories in rotary furnaces give materially longer service when reasonable care is exercised in their installation and proper and slow heating of the lining is provided. The amount of metal charged can greatly influence the number of heats secured from a given lining. With increased tonnages charged, the lining life may be decreased to the extent that the effect may at first seem disproportionate to the increase in the

charge. However, considering the higher temperatures which may be necessary and the additional slagging or washing effect of the metal, this decrease in service life is more readily understood.

ACID ELECTRIC AND OPEN-HEARTH FURNACE REFRACTORIES

32. The refractory problems in an acid electric furnace, as applied in the duplexing process, usually are not difficult. High quality silica brick and ganister, properly applied, give satisfactory and economical service.

Roof

33. With regard to the roof refractories, some developments may be worth mentioning. For example, some operators have adopted water-cooled angles in place of steel rings for supporting the skews. With the water-cooled angles serving as the skew, standard sizes or simple shapes can be adapted for the ring next to the angle. Another development has been the increased use of standard and special rectangular sizes for the roof construction. These both have the advantage of providing greater flexibility to the roof structure, giving it improved resistance to thermal spalling. The use of standard sizes or special rectangular sizes, in many instances, will also provide more prompt deliveries.

Side Wall

34. The side wall requirements are satisfactorily met by high quality silica brick and, in the installation of these, the usual procedure is to lay the brick rather loosely in order to provide the necessary allowance for expansion.

Bottoms

35. The bottoms of acid electric furnaces are usually constructed by ramming ganister-clay mixtures into place. For such mixtures, the clay should be of proper quality and of the proper amount in proportion to the ganister constituent. Plasticity is important and, with its proper development, decreased percentages of clay can be used, with the result that the bottom, while dense, is highly siliceous. The most advantageous sizing of the ganister particles is also an important consideration towards achieving a dense bottom.

36. While the acid open-hearth furnace is used only to a

limited extent in malleable iron production, it offers an example, worthy of note, of the proper handling of silica refractories.

37. The open-hearth furnace is, of course, primarily designed for continuous operation. Therefore, its adaptation to malleable iron melting, with the attendant intermittent operation, presents an interesting refractory application. The open-hearth, as employed, is operated on acid practice. Accordingly, the bottom is siliceous. The side walls and crown are built of silica brick, and it is because of the necessity of maintaining furnace temperatures above the critical range for silica that the operation is particularly interesting from the standpoint of refractories.

38. As previously stated, silica brick attain practically their complete thermal expansion at approximately 1200°F. Between atmospheric temperature and 1200°F. their expansion is very rapid, and provision should be made for gradual heating within this range. Above 1200°F. the expansion is essentially complete, and the brick may be heated and cooled fairly rapidly.

39. Pouring temperatures from the open-hearth, as used for malleable iron, are approximately 2850 to 2880°F. Because of the shop program, so far as the personnel for pouring is concerned, it is desirable, as the usual practice, to tap only one heat per day from the furnace. Therefore, it is the practice to keep the furnace warm with auxiliary burners the remainder of the day, and experience has indicated that if the temperature is held within the range of 1400 to 1800°F. silica brick perform very satisfactorily.

40. In acid open-hearth steel furnaces silica checkers are used successfully. In open-hearth furnaces used for the production of malleable iron, it has been found desirable to use silica brick at the point where the gases enter the regenerator and high heat duty fireclay brick for the remainder of the checkerwork.

41. The acid open-hearth, as used for malleable iron production, does not present any serious refractory problems. The roof life, for example, is very much better than for most open-hearths on steel operation, a two-year service or better being considered normal. Also, it has been found that a 9-in. roof generally is entirely adequate.

Miscellaneous Refractory Applications

42. The auxiliary equipment for malleable iron production

presents some refractory problems and practices which vary quite widely.

Cupola Forehearth

43. The forehearth of the cupola may represent a very severe refractory service in the event that it is used for desulphurizing. The alkali used for the purpose severely attacks the usual silica or alumina-silica refractories at high temperatures. In order to minimize this attack, high density is desirable along with volume stability at high temperatures. The effect of the alkali is to intensify any tendency of the refractory to shrink. Hard-burned high heat duty fireclay brick made by the extrusion process are well adapted to this service, and should be installed very tightly. Trials have been made of various basic brick, super-duty fireclay brick and high-alumina brick in this application and, depending upon the economy of a little extension of refractory life, they may be preferred.

Ladles

44. For the various ladles, high heat duty fireclay brick are being used successfully. For some of the ladle constructions, ramming mixtures work out very well. Usually the mixtures which are highly siliceous, such as those containing ganister as their principal component, are found to be most satisfactory.

Annealing Ovens

45. The refractory requirements of annealing ovens are met, for the most part, by insulating fire brick, high heat duty fireclay brick, and super-duty fireclay brick. High-alumina brick, containing crystalline alumina, and carborundum brick also find application where heavy loads must be supported at high temperatures, or where high thermal conductivity is required. The relatively low temperature of the annealing operation may make the refractories appear rather unimportant. However, in such constructions as a muffle wall or arch, care in design and the proper refractory are required to eliminate the possibility of difficulties resulting from excessive temperatures. Annealing oven bottoms, muffles and car tops also merit care in design and proper choice of refractories. The improved performances and economies which are possible by the application of the most suitable combinations of refractories and insulation to annealing oven construction are worthy of full consideration.

DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

Co-Chairman: A. M. FULTON, Northern Malleable Iron Co., St. Paul, Minn.

J. N. JOHNSON[1]: What has been done with basic lining for desulphurizing hearths?

MR. BRASHARES: The experience has been rather limited. In two or three instances, we have installed a low-iron magnesite brick of about 90 per cent MgO content. Where it has been necessary to make the repairs only over the week-end, the service extension has not been sufficient to go over to the second week-end.

R. GREENE[2]: In lining ladles with magnesite brick, do you find any great amount of penetration of the acid slag around the top of the iron level?

MR. BRASHARES: Do you mean in lining the ladles with basic brick?

MR. GREENE: Did I understand you to say that you lined the forehearth or the ladle with magnesite brick?

MR. BRASHARES: Just the forehearth.

MR. GREENE: Actually what happened: Did you get any penetration there, an extreme amount of penetration right through the brick itself?

MR. BRASHARES: Mechanically, penetration did take place. That is, the brick was chemically more resistant than the clay brick, but it had higher porosity with the attendant higher mechanical penetration. With the differences in texture which then prevailed between the face of the brick and the back, I am inclined to believe there was some "cracking off," although they were reported as merely consumed.

MR. GREENE: Is there any record of trials in which soda slag was used? Did you use soda ash for desulphurizing in such an installation? Is it that to which you refer?

MR. BRASHARES: Yes.

W. R. JAESCHKE[3]: I'd like to ask Mr. Brashares to expand upon the use of magnesite linings in cupolas other than those dealing with a dephosphorizing process, as for straight malleable iron melting.

MR. BRASHARES: So far this has been very much of an unexpected development, not so much promoted as adapted in the steel plant in which this cupola was operating on a reasonably high steel charge.

MR. JAESCHKE: I thought some were trying this out at malleable plants with straight melting, without any special process connected with it.

MR. BRASHARES: No. If we had offered any recommendations in this case, it would have been a very hard-burned magnesite. The plant has gone ahead and used the chemically-bonded, with very good results. We know, from some other small trials, that this will have to be followed rather carefully. That is, expansion is going to have to be very care-

[1] Union Malleable Iron Co., East Moline, Ill.
[2] Detroit Brass and Malleable Works, Wyandotte, Mich.
[3] Whiting Corp., Harvey, Ill.

fully provided, and the utility of magnesite will depend upon the slagging conditions.

C. H. CRAWFORD[4]: I would like to have some figures in reference to air furnace melting, upon comparisons of the life of refractories for a bottom and the life of the lining on the sides and the bungs.

MR. BRASHARES: I seem to remember the figures—about 1, 2, 4 as the ratio of brick used, these being respectively bungs, bottoms and side walls.

MR. JAESCHKE: You might get about 100 heats on batch melting furnace bottoms, approximately 25 heats on the side walls and probably 50 heats on the bungs—a ratio of about that order.

MR. CRAWFORD: How does the brick bottom and the sand bottom compare as to cost, and what are the advantages of one over the other?

MR. BRASHARES: Regarding costs, I do not have figures at hand. I have noticed that some of the papers, which have been given here, stated that, for the smaller capacities of furnaces, sand was preferred. With the higher capacities, brick were preferred.

D. TAMOR[5]: I question the figures of 25 heats on the side walls and 50 on the bottom.

MR. JAESCHKE: That would be on the basis of two heats a day. Those are actual figures from plants batch melting on a brick bottom.

J. A. KAYSER[6]: Of course, you do not find a great many batch melting furnaces using brick bottoms.

MR. JAESCHKE: The figures given are from places, like Malleable Iron Fittings Co., where they were batch melting on a brick bottom.

MR. KAYSER: I think, on duplexing, that if you get a week from side walls, that is about as much as anybody expects, and I believe the figures on bottom life are likely to be somewhere about 5,000 tons.

MR. JOHNSON: That was the point I want to clarify; in duplexing, we have found that the refractory cost and the tonnage produced were not related. It was a matter of days operated. If tonnage was down, the refractory cost per ton was up. With 50 tons of melt, the refractory cost per month was quite as high as it was when we were melting 150 tons per day. It is the preheat period that seems to damage the bottom brick, in particular, as well as the side wall brick.

CHAIRMAN JOSEPH: We have heard about 25 heats on the air furnace. How about the cupola melting unit? How many heats do you get on that?

For instance, in duplexing; is there anyone who runs a cupola over an entire day of, say, 16 hr., and then chips it out and uses it over the next day without lining it up?

MR. TAMOR: Do you mean without chipping out the melting zone?

CHAIRMAN JOSEPH: Yes, and replacing it with new blocks.

MR. JOHNSON: Yes, we are doing that at this particular time, but our tonnage is not quite up to standard. We are melting 60 tons per day in a 48-in. melting zone and, because we have a forehearth on only

[4] David Bradley Manufacturing Works, Bradley, Ill.
[5] American Chain Malleable Foundry, York, Pa.
[6] Laclede Christy Clay Products Co., St. Louis, Mo.

one of our cupolas and want to operate that 4 of 6 days, we just chip out the slagging trough and run that cupola the second consecutive day without repair work in the melting zone. We do, of course, chip off around the doors where there is slag.

CHAIRMAN JOSEPH: How many hours do you operate?

MR. JOHNSON: That cupola is in blast about 7 hr. on each shift.

CHAIRMAN JOSEPH: I had reference to a longer run; a 16-hr. run, well up to the maximum of the cupola, with maximum tons per hr.

MR. GREENE: I was under the impression that there was a firm in Lansing, operating its cupola 6 or 7 days a week by merely banking it at night with coke.

CHAIRMAN JOSEPH: That was the water-cooled banking.

MR. GREENE: You referred to the straight practice?

CHAIRMAN JOSEPH: It does not really matter. You can get it if you can run for more than one day. They ran for 6 days, I understand, but I do not believe that they are doing it now.

MR. JOHNSON: Our steel foundry is running its cupola from 24 to 33 hr., but on straight heats. The cupola is not shut down at all.

CHAIRMAN JOSEPH: I have reference to malleable iron, where it is necessary to control the carbon and silicon-manganese to get a control, not merely melting alone, as they do in some of the steel cupolas where they melt the metal—I am referring to a controlled cupola operation.

MR. KAYSER: Mr. Brashares mentioned something about using silica in cupola and, also, in Brackelsburg furnaces, and the necessity of calculating the expansion of silica in order to allow for it. I would like to have a little more detail on that. For years we have been trying to find out how to calculate expansion and allow for it, and work it out that way.

Also, the question of how, after making the calculation and turning it over to the user of the silica, we get him to use the right amount of expansion and arrive at the correct lining.

MR. BRASHARES: Mr. Kayser has really presented a problem. We now have this, both with silica and magnesite, and since the latter is the more difficult I will illustrate with silica.

In figuring the silica, we have to count upon about 5/32-in. normal expansion, and we have recommended a slightly less than theoretical, or (you can check me on your present practice) ⅛-in. expansion, both longitudinally and circumferentially, and that the lining be laid just as tightly as possible.

In laying the lining in any rotary, the ring construction is used and a final key is driven. In order to get our expansion allowance to come out right; that is the way we have done it.

MR. KAYSER: What expansion material are you using to arrive at that expansion, to make a tight lining?

MR. BRASHARES: We have furnished a hard pasteboard. It was really hard, like wood. I doubt if there would be much actual compression in it.

MR. KAYSER: It would burn out at an early enough temperature.

MR. MASON: We use 30-lb. regular roofing felt.

MR. BRASHARES: He would have to allow a little leeway.

MR. JAESCHKE: I think he used the roofing paper in the joints circumferentially, and the hard pasteboard in the joints every 12 or 13½ in. in the longitudinal direction.

MR. BRASHARES: Specific expansion allowance is a difficult thing to recommend, because it has to be made with a reservation depending upon how the brick are laid.

Factors Affecting the Ductility of Cast Steel

By George A. Timmons*, Detroit, Mich.

Abstract

Ductility in cast steels is affected by several factors among which are the following: Porosity, character and distribution of non-metallic inclusions, temper brittleness and the distribution of the micro-constituents resulting from the decomposition of austenite. The general aspects of ductility in cast steel and the present methods used for its evaluation are discussed. The effects of porosity, grain boundary sulphide inclusions and temper brittleness are briefly discussed. Particular attention is given to the effects upon ductility of the segregation of alloying elements occurring during solidification. It is shown that the greater segregation resulting from slow rates of solidification reduces the hardenability of the steel and that the solidification pattern determines the distribution of the micro-constituents formed from the decomposition of austenite when the cooling rate from the austenitizing temperature is less than the critical quenching rate for the steel. Non-uniform distributions of a different micro-constituent in the predominant or "matrix" constituent tend to reduce the ductility of the steel by increasing the resistance to plastic deformation with respect to the resistance to fracture.

1. The use of cast steel as a structural material for many applications has been restricted, owing to its low ductility when compared to wrought steel of similar composition at the same hardness. Not only has the ductility of steel castings been lower than that of forgings or rolled shapes, but considerable difficulty has been experienced in producing *consistently* castings which will satisfy the specifications which must be met in the various classes established for the control of quality. Much effort has been expended to improve the ductility of steel castings and to develop processes and techniques which would give higher values consistently. These efforts have been concerned with improvements in mold design, gating, risering, venting, etc., to eliminate shrinkage defects and "hot tears"; with improvements in furnace practice, particularly with regard to controlling the character and distribution of non-metallic inclusions and the elimination of dissolved gases; with the

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selection of the proper heat treatment to develop the best combination of properties; and with the use of certain alloying elements which have been found to benefit cast steel by virtue of their effects upon the stability of austenite, making the heat treating of heavy sections a commercial possibility.

2. The purpose of this paper is to examine various factors which must be considered in order to obtain the maximum ductility in a steel casting. The essence of ductility in metals is briefly considered and the methods or criteria used for its evaluation are discussed. The lack of continuity, due to porosity and grain boundary non-metallic inclusions, is reviewed only briefly since the literature contains numerous references to this subject. The major portion of the paper is devoted to a study of the effects upon ductility of the segregation of alloying elements which occurs during solidification and of the solidification patterns formed. It is shown that this segregation has an influence upon the hardenability of the steel and that when the steel is cooled from the austenitic state at less than the critical cooling rate for the average composition, the resulting distribution of different micro-constituents is responsible for the ductility of the tensile bar or the toughness of a notched specimen. The phenomenon of "temper brittleness" is given due consideration.

3. Owing to the status of the alloy situation in 1942 and at the beginning of 1943, many castings were made of a medium carbon, manganese-molybdenum composition. It has been considered expedient to devote considerable attention to the development of the best properties of this composition. Although many of the data presented herein pertain to the manganese-molybdenum steel, the general considerations involved are applicable to all cast steels falling within the same general group classifications.

DUCTILITY AND CRITERIA FOR ITS EVALUATION

4. The term "ductility" is applied to the ability of a metal to withstand deformation before fracture. The greater the amount of plastic deformation occurring before fracture, the greater is the ductility of the steel. The ductility of cast steel is usually evaluated by the elongation and the reduction of area obtained from the standard tension test, by the angle of bend before fracture obtained in a bend test, or by the amount of energy absorbed in breaking a notched-bar—the so-called "impact test." When a metal is ductile, the fracture caused by final failure is "fibrous"

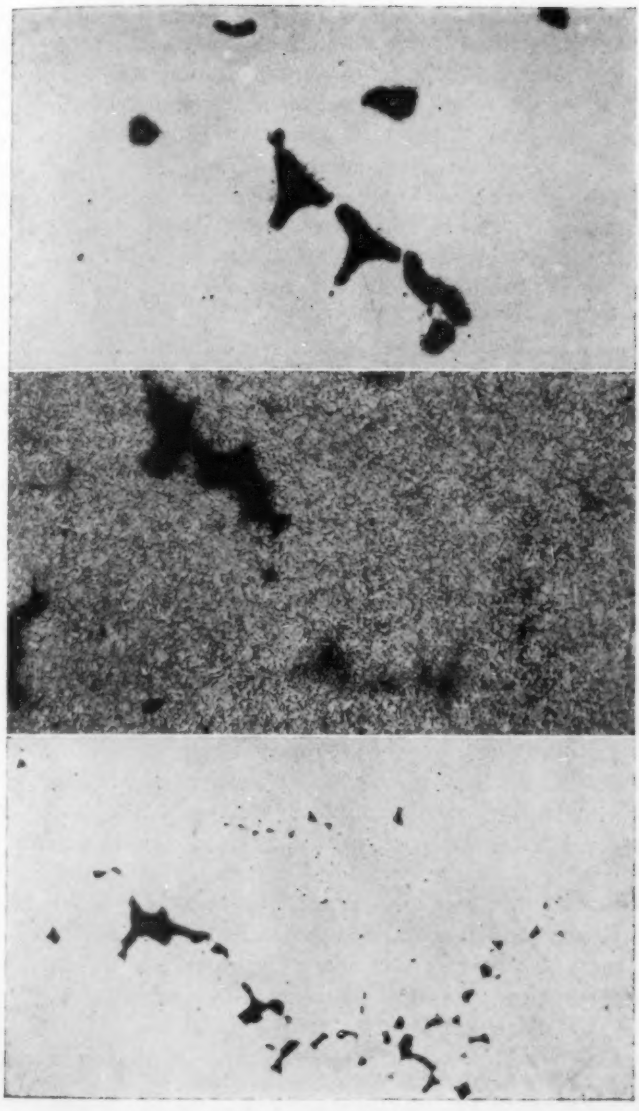


FIG. 1—EXAMPLES OF SHRINKAGE VOIDS FOUND IN STEEL CASTINGS. MAGNIFICATION ×100.

but when a brittle failure occurs the fracture has a "granular" appearance. If plastic deformation occurs before fracture, a greater expenditure of energy will be required to produce failure than if the part breaks in a brittle manner. Studies of the problem have shown that ductility and total work (to cause failure) are dependent upon the relationship between "resistance to plastic deformation" and "resistance to fracture." The resistance to plastic deformation is usually considered as "flow stress" and is the tensile stress required to produce plastic deformation in the standard tension tests (or the "yield strength"); the resistance to fracture may be interpreted as a technically determinable stress necessary to cause fracture[1*], such as the *actual* stress required to produce failure of a tension test bar (this stress may be computed by dividing the load at fracture by the area of the cross section at fracture). If the "flow stress" is attained before the resistance to fracture, failure will be accompanied by plastic deformation, but if the resistance to fracture is attained before the flow stress, failure will occur in a brittle manner. The energy absorbed in causing failure under the former condition will be greater than when the latter condition prevails.

5. Plastic deformation occurs by slip and is accompanied by work hardening which tends to increase the resistance to further slip. As plastic deformation proceeds under a given state of stress, the flow stress increases until the resistance to fracture is finally attained and cohesive failure occurs. Since ductility values depend upon the amount of plastic deformation that occurs before fracture, any factor which tends to increase the resistance to flow with respect to the resistance to fracture will reduce the ductility of the steel and make it more susceptible to failure in a brittle manner. Phenomena tending to increase the rate of strain-hardening will also reduce the ductility of a steel since they will control the rate of increase of flow stress as plastic deformation progresses and thereby limit the amount of deformation occurring before the resistance to fracture is attained. The relationship between the resistance to flow and the resistance to fracture is influenced not only by the characteristics of the metal itself but by such variables as combination of stress, velocity of deformation, and temperature.

Tension Test

6. The standard tension test, using a specimen consisting of a

* Superior numbers refer to bibliography at the end of the paper.

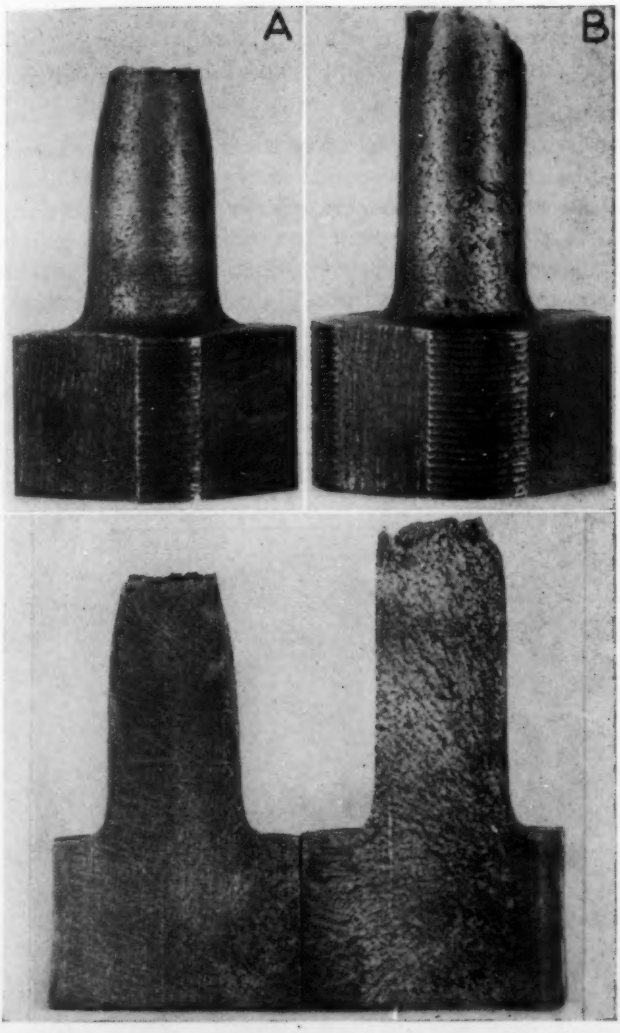


FIG. 2—MACRO-ETCHED TENSILE SPECIMENS. THE TWO SPECIMENS WERE MACHINED FROM THE SAME CASTING WITHIN A DISTANCE OF 6-IN. BOTH SPECIMENS WERE ETCHED SIMULTANEOUSLY IN BOILING 1:1 HYDROCHLORIC ACID SOLUTION. THE POROSITY OF SPECIMEN (B) REDUCED THE ELONGATION AND THE REDUCTION OF AREA.

smooth cylinder which is loaded in simple tension, determines the ductility of a steel under favorable conditions. Under these conditions the *maximum normal stress*, that component of the applied stress tending to cause cohesive failure, is twice the value of the *maximum shear stress*, that component of the applied stress tend-

ing to cause flow. If the tension test indicates that a cast steel possesses low ductility, structures made of that steel may be expected to fail in a brittle manner with a low absorption of energy.

Notched-Bar or Impact Tests

7. A more sensitive criterion of the ductility of a steel would be a test in which the stress conditions were such that the maximum normal stress was considerably greater than twice the maximum shear stress. The notched-bar test satisfies such a requirement. Since a correlation exists between ductility and the total work required to produce failure, ductility may be quantitatively evaluated by measuring the energy absorbed in fracturing a standard specimen. The Charpy and Izod tests offer a convenient method for measuring energy absorption and may be used to evaluate ductility. Although these tests are frequently referred to as "impact tests" they are more correctly regarded as "notched-bar" tests. They do not simulate conditions of shock in service since

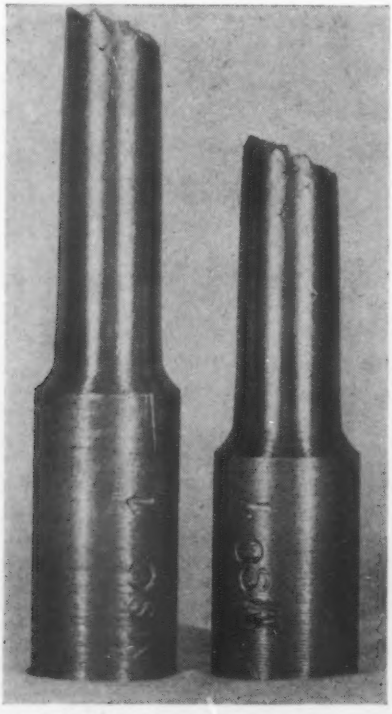


FIG. 3—"CHECKS" OR "CROW'S FEET" ON SURFACE OF GAUGE LENGTH OF BROKEN TENSILE BAR CONTAINING SHRINKAGE POROSITY.

the rates of loading in the testing machines are considerably slower than the rates of load application in most service conditions. The tests should be viewed as criteria for determining whether or not a structure made of the steel under consideration would be susceptible to failure in a brittle manner.

8. Although the notched-bar test is considerably more sensitive than the tension test for the evaluation of ductility, when these tests are run at room temperature only, they may not indicate a difference in the ductility of two steels which can otherwise be shown to exist. As the temperature of a metal is lowered, flow resistance increases fairly rapidly while the cohesive limit is affected only slightly, so the susceptibility to failure in a brittle manner becomes greater. Since the notched-bar test provides the greater ratio of maximum normal stress to maximum shear stress, metals will become brittle at higher temperatures in this test than in the standard tension test. When steels are notched-bar tested over a wide range of temperature above and below room temperature, and the total work required to produce fracture is plotted against temperature, it has been found that within a comparatively narrow temperature range, the total work drops off rapidly and a transition from a fibrous to a granular fracture occurs. Above this more or less critical temperature range the values are uniformly high and the fractures are fibrous, but below it the values are uniformly low and the fractures are granular. The temperature range at which this transition occurs depends upon the hardness and microstructure of the steel; the spatial stress ratio as influenced by the sharpness of the notch, the width and size of the specimen; and the velocity of deformation. The temperature range is raised and contracted by increasing the sharpness of the notch, by increasing the over-all size of the specimen, by increasing the width of the specimen, and by increasing the velocity of deformation. However, if the same standard specimen is used throughout a series of notched-bar tests run over a range of temperatures and all other factors are held constant, the ductility of two or more steels, or the effectiveness of different heat treatments, may be compared by noting the temperature at which the drop in energy occurs. Steels which exhibit the drop in energy at higher temperature levels are more likely to break with a brittle fracture and a lower absorption of energy at normal atmospheric temperatures than a steel whose transition temperature is very low. The energy-temperature curve provides a sensitive criterion for the evaluation of ductility in

steel castings. This method of testing has been used to detect "temper brittleness" in the manganese-molybdenum cast steel.

9. Most cast parts are of complicated shape. There exist changes in direction of elements, changes in section size, and notches. Loading conditions usually result in complex distributions of stress in which the maximum normal stress is several times the maximum shear stress and the tendency to fail in a brittle manner is high. Brittle failures, therefore, often occur, due more to faulty design than to insufficient ductility of the steel. However, since one of the chief values of casting steel parts lies in the feasibility of producing complicated shapes, it becomes the problem of the foundrymen to produce steel as ductile as possible to reduce brittle failures to a minimum. Machine parts, railway castings and others are frequently subjected to loading conditions in which the velocity of deformation is relatively high and some of these castings are subjected to service conditions at low atmospheric temperatures. With such castings it is almost mandatory that the steel be produced to give as high ductility as is compatible with other required specifications and the subzero-notched-bar tests have been adopted as criteria for evaluating castings for such service.

POROSITY

10. Porosity in steel castings is one of the important factors contributing to reduced ductility. Porosity may result from the evolution of gas during solidification. When it is due to this cause, holes are formed which are nearly spherical in shape, and the surface of the surrounding metal is smooth. The surface may be clean and bright, or it may be dull and scaled, depending upon the nature of the gas which was driven out of solution as the metal froze. This type of porosity is generally traced to improper furnace practice used in processing the heat of steel or it may be traced to an excessive moisture content in the mold. Difficulties due to these causes may be remedied by changes in the methods of deoxidation (or "degasification") and by controlling the moisture in the mold material more carefully.

11. Porosity may also result from shrinkage. As steel solidifies an appreciable increase in density occurs. If a location is not adequately fed by molten metal during solidification, the lack of liquid metal to satisfy the contraction in volume accompanying the change from the liquid state to the solid state is responsible for

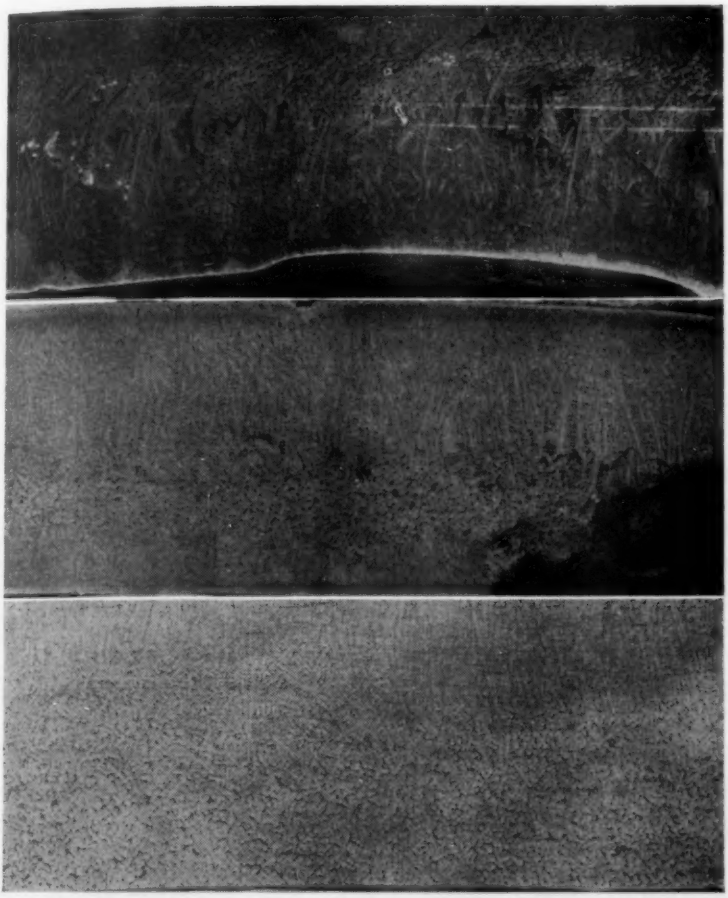


FIG. 4—MACRO-ETCHED CROSS SECTIONS OF THREE 1½-IN. CAST STEEL PLATES AT LOCATIONS APPROXIMATELY 12-IN. FROM THE NEAREST EDGE.

the formation of voids. These voids may exist as large cavities in the metal or the "void volume" may exist as a series of smaller, interdendritic voids such as those shown in Fig. 1.

12. Voids of either type constitute discontinuities in the metal and greatly reduce both the reduction of area and the elongation of a tension test specimen. Figures 2, 5A and 5B show macro-etched sections of tensile specimens which illustrate this influence of porosity on the ductility of steel castings. In each case the tensile bars were machined from the same casting, but, while one bar was composed of sound metal, the other bar contained porosity

due to shrinkage. The shape of each bar at the fracture indicates the ductility.

13. When such porosity occurs, even the most beneficial heat treatments fail to produce satisfactory ductility. Tensile specimens will generally exhibit "checks" or "crow's feet" as illustrated in Fig. 3. The yield and tensile strengths are certainly reduced by such microscopic porosity, but, unless the porosity is unusually bad, the lowering of these values may escape detection in the routine tensile test. The elongation is definitely reduced by relatively small amounts of porosity. The reduction of area and room temperature notched-bar values are especially sensitive to such discontinuities in the metal.

14. Porosity is one of the big problems encountered in producing sound plate castings. An ideal mold design for large plates would provide adequate liquid metal at every location to satisfy the contraction in volume accompanying solidification, regardless of pouring temperature, rate of solidification, etc. Such a mold could be considered "fool-proof," but the recovery would probably be so low that production would be commercially impractical. The foundryman must compromise and design his plate mold in such a manner that, with moderate control over the other factors, he can produce sound castings consistently with a recovery compatible with the economics involved. Among the factors which influence the porosity of such castings are the pouring temperature, the rate of pouring, the mold conditions, and the composition of the metal as it affects the degree of undercooling.

Rate of Solidification

15. The pouring rate, the pouring temperature, and the mold material influence the rate of solidification. When the pouring temperature is high, more heat must be removed from the molten metal before solidification starts and the rate of solidification may be slow. However, the metal which comes in contact with the mold freezes quickly. If the mold conditions are such that the top of the casting freezes quickly in a layer sufficiently thick to permit it to hold its position with a quantity of molten metal trapped between top and bottom, there cannot be ample metal to satisfy completely the shrinkage attending solidification and some interdendritic voids will be developed. Depending upon the relationship between the rate of solidification progressing from the bottom and the rate of solidification progressing from the top, the porous section will be nearer the bottom or nearer the top. Lower pouring tem-

PLATE A PLATE B PLATE C

FIG. 5—MACRO-ETCHED CROSS SECTIONS OF TENSILE SPECIMENS FROM THREE 1½-IN. CAST STEEL PLATES.

Properties	*Edge*	*Bottom*	*Top*	*Edge*	*Bottom*	*Top*	*Edge*	*Bottom*	*Top*
BRINELL HARDNESS NO.	285	269	269	255	235	235	255	223	217
YIELD POINT, LB. PER SQ. IN.	116,600	115,500	118,800	103,400	89,700	91,300	109,900	93,000	99,000
TENSILE STRENGTH, LB. PER SQ. IN.	141,900	134,000	140,000	127,000	111,100	112,200	125,100	109,500	115,000
ELONGATION IN 2-IN., PER CENT	16.0	5.0	14.8	15.5	4.0	4.5	18.0	16.5	18.8
REDUCTION OF AREA, PER CENT	42.8	11.5	31.2	38.2	5.8	7.4	52.5	52.5	51.4

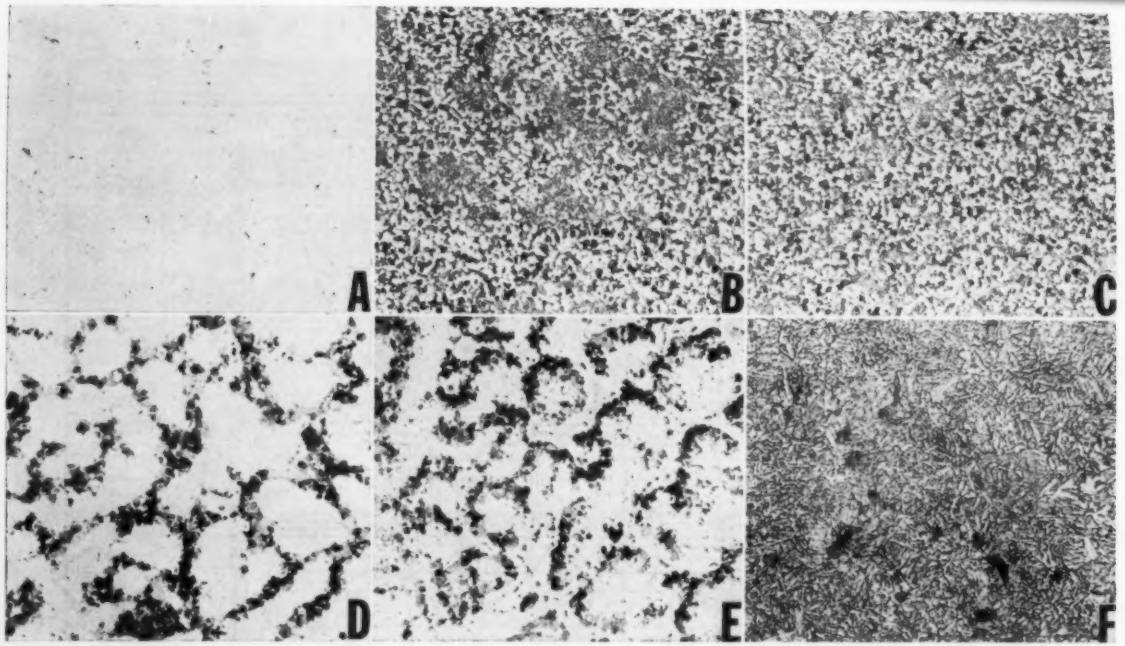
peratures and slower pouring rates allow the metal to solidify more uniformly with the formation of fewer voids.

16. Figure 4 illustrates macro-etched cross sections of 3 different plate castings of manganese-molybdenum steel, showing variations in the solidification pattern and the amount of porosity present from top to bottom. Figure 5 shows macro-etched cross sections of tensile specimens from the same plates with the data obtained on each specimen tabulated below. The 3 plates were cast in a horizontal position. All 3 plates were sound along the edges and to a distance of from 3- to 4-in. from each edge. At these edges, the rate of solidification was rapid, and ample metal was present to satisfy the volume contraction accompanying solidification. Samples from the edge sections were sound throughout and exhibited satisfactory ductility as measured by the tension test. At a distance 12-in. from the edges, solidification took place without adequate feeding, and shrinkage porosity resulted. The illustrations show that the bottom portions of plates A and B of Fig. 5 contained more porosity than the top portions of the same plates. The top portions had higher values for elongation and reduction of area. Plate C was uniformly sound throughout.

CHARACTER AND DISTRIBUTION OF NON-METALLIC INCLUSIONS

17. Ranking among the greatest contributions to the study of poor and inconsistent ductility in cast steel were the investigations of the eutectic-type, grain boundary, sulphide inclusions conducted and reported by Sims and collaborators[4, 5]. Figure 6A illustrates a typical example of this type of non-metallic inclusion showing the characteristic grain boundary distribution. The presence of these inclusions has been found to be responsible for poor ductility in castings, even when all other conditions conducive to high ductility have been provided.

18. The failure of a tension test bar, containing these eutectic-type inclusions in the grain boundaries in sufficient amounts, usually occurs with the formation of "crow's feet" or "checks" on the cylindrical surface of the gauge length in the vicinity of the fracture. The actual fracture of the specimen often starts at one of these surface cracks which, in effect, acts as a sharp notch and thereby contributes toward a reduction in the amount of plastic deformation taking place before failure. When only a few of these inclusions are present in a steel casting, the ductility will not be as greatly impaired as when the number is high. As in the case



D—2 Per Cent Nital X100 *E—2 Per Cent Nital X100* *F—2 Per Cent Nital X500*

FIG. 6.
A—Characteristic Distribution of Sulphide Inclusions in Heat No. 2668.
B—Typical Microstructure of Steel No. 2667—Normalized and Drawn.
C—Typical Microstructure of Steel No. 2668—Normalized and Drawn.
D—Typical Microstructure of Steel No. 2667—Annealed.
E—Typical Microstructure of Steel No. 2668—Annealed. Note Grain-Boundary Sulphide Inclusions.
F—Typical Microstructure of Steel No. 2668—Quenched and Drawn, Showing Positions of Inclusions. The Inclusions Have Had No Effect Upon the Structure Resulting from the Decomposition of Austenite.
(REDUCED SLIGHTLY IN REPRODUCTION)

of porosity, the values for reduction in area and for the notched-bar tests are most sensitive to the presence of the grain boundary non-metallics. It is apparent that the discontinuity of the metal is responsible for the surface cracks and the reduction in plastic deformation before failure, since the behavior of the test specimens is similar for steels exhibiting either porosity or the chain-like grain boundary inclusions. When the tension test bar fails with checks appearing at the surface, a metallographic examination is required to determine which factor is responsible for the poor ductility.

19. The work of Sims and Dahle indicated conclusively that the presence of the eutectic-type, grain boundary inclusions was associated with sulphur contents over 0.03 per cent and an addition of a critical amount of aluminum for deoxidation. It was

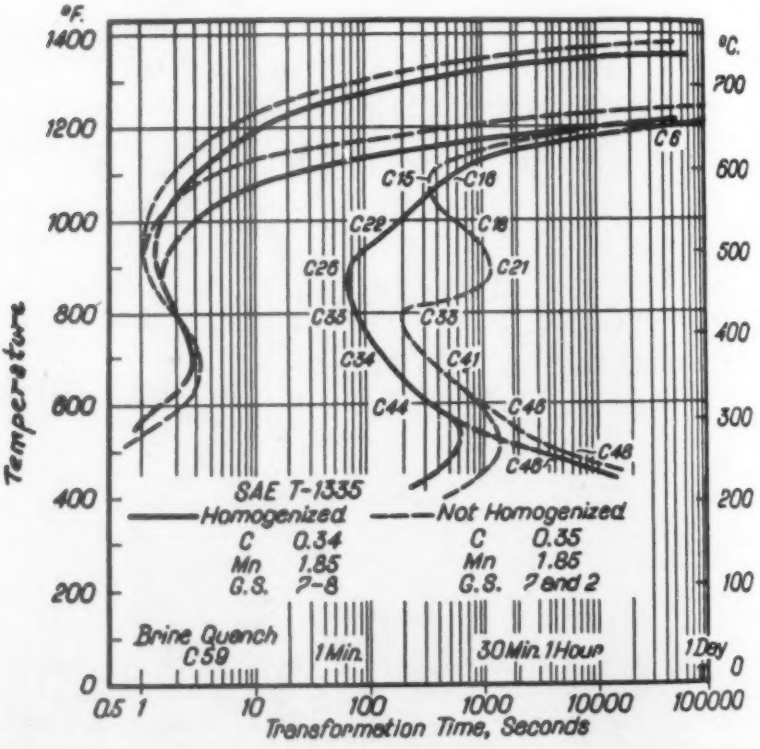


FIG. 7A—COMPARATIVE ISOTHERMAL TRANSFORMATION CURVES FOR A CARBON-MANGANESE STEEL (SOCIETY OF AUTOMOTIVE ENGINEERS T-1335) BEFORE AND AFTER HOMOGENIZATION. HOMOGENIZED—SOLID LINES; NOT HOMOGENIZED—BROKEN LINES7.

shown that with sulphur contents under 0.03 per cent, no appreciable loss in ductility resulted from aluminum additions, and that with sulphur contents greater than 0.03 per cent, aluminum additions could be used safely, provided they were sufficiently below or sufficiently above a certain critical value. The mechanism of the formation of the detrimental eutectic, grain boundary inclu-

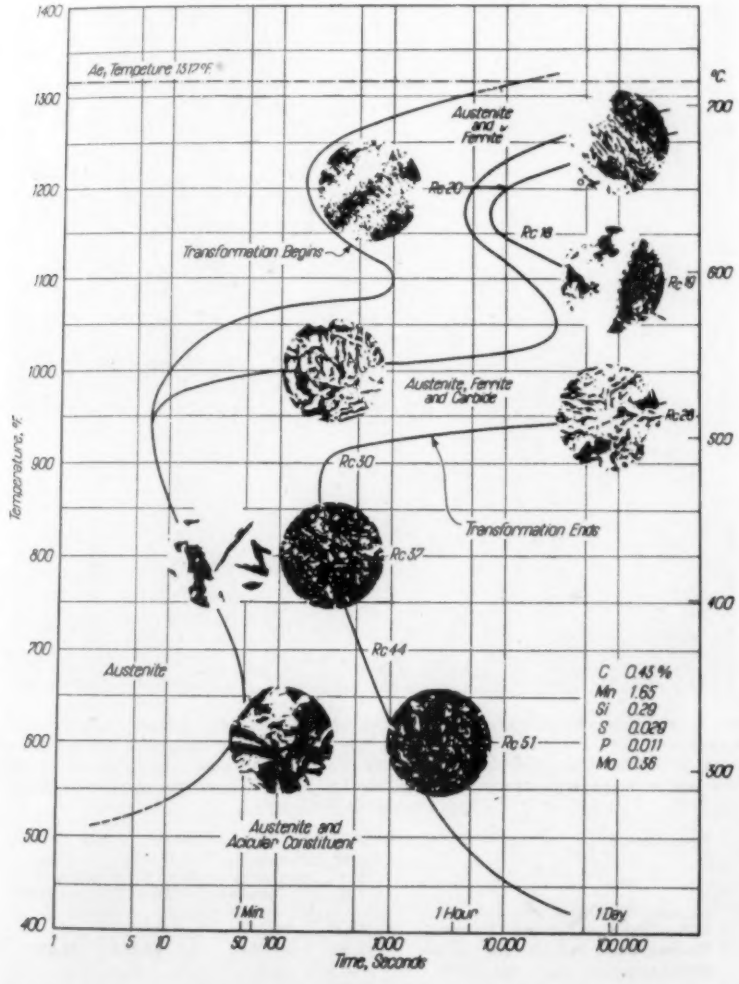


FIG. 7B—ISOTHERMAL TRANSFORMATION "S" CURVES OF 0.43 PER CENT CARBON-1.65 PER CENT MANGANESE STEEL CONTAINING 0.36 PER CENT MOLYBDENUM. AUSTENITIZING TEMPERATURE 1550°F. AUSTENITE GRAIN SIZE 8. ORIGINAL MICROGRAPHS AT x1000.

sions was explained as a matter of solubility of iron-and manganese-sulphides in molten iron, this solubility being influenced by the oxide content of the steel.

20. Briefly, higher oxide contents reduced the solubility of the sulphides so they precipitated before solidification had progressed very far and the shape was essentially spheroidal with a random distribution. When the oxide content was low, as the

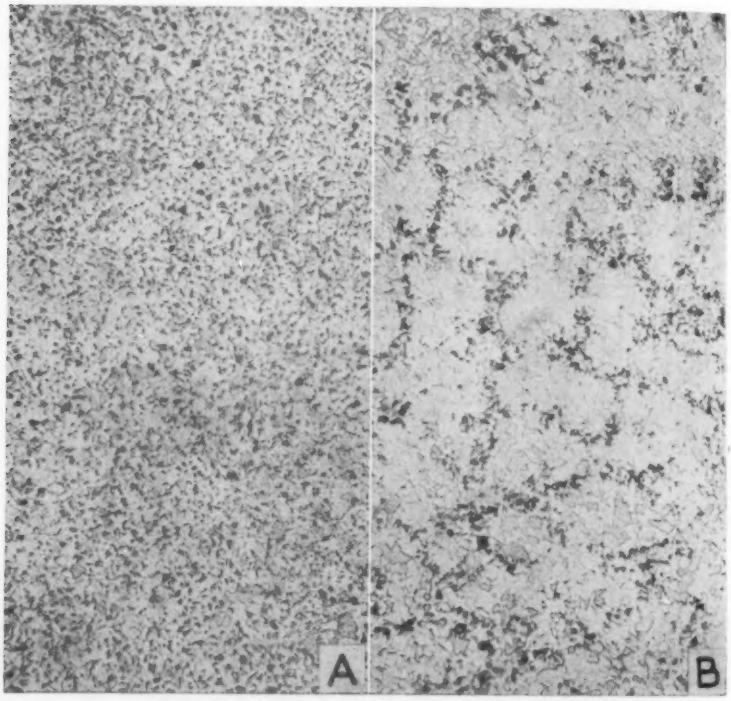


FIG. 8—MICROSTRUCTURES DEVELOPED IN STEEL OF 0.14 PER CENT CARBON, 0.67 PER CENT MANGANESE, 0.50 PER CENT MOLYBDENUM, 0.40 PER CENT SILICON, 0.16 PER CENT SULPHUR AND 0.032 PER CENT PHOSPHORUS BY VARYING SLIGHTLY THE RATE OF COOLING FROM AN AUSTENITIZING TEMPERATURE OF 1600°F. HEAT TREATMENT OF ONE-IN. SQUARE SECTIONS IS AS FOLLOWS:

Properties	*(A)* 1800°F., Air Cooled 1600°F., Air Cooled 1200°F., Air Cooled		*(B)* 1800°F., Air Cooled 1600°F., Furnace Cooled 1200°F., Air Cooled	
Brinell Hardness No.	126		121	
Yield Strength, lb. per sq. in.	43,500	44,000	43,800	44,100
Tensile Strength, lb. per sq. in.	67,700	67,500	65,400	65,700
Elongation in 2-In., per cent	35.0	36.2	32.5	33.0
Reduction of Area, per cent	70.0	70.0	61.0	62.6
Izod, ft. lb.	88.5		35.2	
Fracture	Fibrous		Granular	

result of an addition of aluminum (or other potent deoxidizers), the solubility of the sulphides was high and they remained in solution until the last metal froze. In this case, they solidified with the metal in the form of an eutectic, and being the last liquid to freeze, this eutectic would be forced to solidify at the interstices

Table 1

RESULTS OF MECHANICAL PROPERTY TESTS ON STEELS NOS. 2667 AND 2668

NOTE: A.C. = Air Cooled. F.C. = Furnace Cooled. W.Q. = Water Quenched.

Heat No.	*2667 per cent*			*2668 per cent*
Carbon	0.29			0.29
Manganese	0.77			0.73
Silicon	0.42			0.43
Sulphur	0.014			0.044
Phosphorus	0.012			0.014
Molybdenum	0.52			0.52
Aluminum added to heat	0.06			0.06
Heat Treatment No. 1—1800°F., A.C.; 1600°F., A.C.; 1250°F., A.C.				
Brinell Hardness No.	187	187	183	179
Yield Point, lb. per sq. in.	55,000	55,000	54,800	53,900
Tensile Strength, lb. per sq. in.	94,300	93,700	91,100	90,800
Elongation in 2-in., per cent	18.3	19.5	16.4	20.0
Reduction of Area, per cent	31.9	31.9	25.1	33.8
Izod, ft. lb.*		34.2		23.8
Heat Treatment No. 2—1800°F.; 1600°F., F.C.				
Brinell Hardness No.		145		143
Yield Point, lb. per sq. in.		46,200		46,200
Tensile Strength, lb. per sq. in.		77,600		76,900
Elongation in 2-in., per cent		25.8		22.0
Reduction of Area, per cent		42.2		28.2
Izod, ft. lb.**		28.7		18.4
Heat Treatment No. 3—1800°F., 1600°F., W.Q.; 1250°F., W.Q.				
Brinell Hardness No.		228		217
Yield Point, lb. per sq. in.		96,800		85,300
Tensile Strength, lb. per sq. in.		113,300		105,000
Elongation in 2-in., per cent		20.0		10.0
Reduction of Area, per cent		53.3		17.7
Izod, ft. lb.**		57.1		21.9
Heat Treatment No. 4—1800°F., 1600°F., W.Q.; 1275°F., W.Q.				
Brinell Hardness No.	187	187	187	187
Yield Point, lb. per sq. in.	78,100	77,000	74,000	75,900
Tensile Strength, lb. per sq. in.	93,500	93,300	91,000	91,700
Elongation in 2-in., per cent	26.3	25.5	24.5	22.5
Reduction of Area, per cent	62.8	60.8	51.2	49.9
Izod, ft. lb.*		62.9		27.0

* Izod values average of 6 individual breaks.
** Izod values average of 3 individual breaks.
Yield values measured by "drop of beam" method.
All heat treatments: bars 1-in. x 1½-in. x 5-in. placed in furnace at indicated temperature, held 2 hours, except treatment No. 4 in which the samples were held at 1275°F. 4 hours.

of the dendrites. The presence of excess aluminum resulted in the formation of aluminum sulphides which were less soluble in molten iron (low in oxide content) than iron-or manganese-sulphides. The aluminum sulphides, therefore, were precipitated from the molten bath before solidification was complete and were distributed at random throughout the metal.

21. Using the results of this investigation, many foundries, now forced to use low grade scrap which results in higher sulphur contents in acid heats, are producing castings successfully by adding excess aluminum whenever any aluminum additions are required to eliminate pin holes in castings poured in green sand molds.

Effects of Non-Metallic Inclusions

22. The effects of these grain boundary, non-metallic inclusions may be illustrated by a comparison of two heats of steel which vary only in the number and distribution of such sulphide inclusions. Table 1 presents the data obtained from tensile and Izod tests conducted on two similar heats of steel. The heats were produced in the laboratory in exactly the same manner. All conditions were held constant throughout the experiment except that one heat contained 0.044 per cent sulphur, while the other contained only 0.014 per cent sulphur. The mechanical properties were determined after heat treating different sections of the two castings according to 4 different schedules. All sections were 1- x 1-1/2- x 5-in., and they were all air cooled from 1800°F. before the final heat treatments were applied. Three schedules varied only in the rate of cooling from the second austenitizing temperature of 1600°F.: (a) furnace cooled, (b) air cooled, and (c) water quenched. The fourth treatment varied from the third in that a higher draw temperature and longer time at heat were employed to produce a lower hardness.

23. All specimens from heat No. 2668 contained the eutectic sulphide inclusions in the interstices of the original austenite dendrites as shown in Figs. 6A, 6E and 6F. The specimens from heat No. 2667 exhibited only a few sulphide inclusions which were distributed at random throughout the metal. The data presented in Table 1 indicate that with every heat treating schedule, the steel containing the chain-like sulphide inclusions possessed inferior ductility. The difference in Izod values was less pronounced when the steels were compared in the normalized-and-drawn condition and after annealing than when they were compared after quenching and drawing. Water quenching and drawing produced a

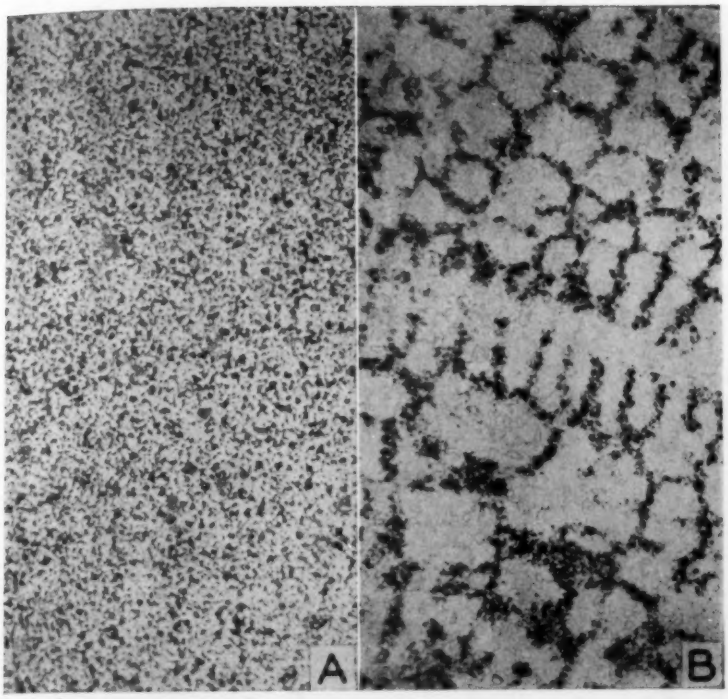


FIG. 9—MICROSTRUCTURES DEVELOPED IN STEEL OF 0.21 PER CENT CARBON, 0.70 PER CENT MANGANESE, 0.54 PER CENT MOLYBDENUM, 0.47 PER CENT SILICON, 0.016 PER CENT SULPHUR AND 0.026 PER CENT PHOSPHORUS BY VARYING SLIGHTLY THE RATES OF COOLING FROM AN AUSTENITIZING TEMPERATURE OF 1600°F. HEAT TREATMENT OF ONE-IN. SQUARE SECTIONS—(A) 1800°F., AIR COOLED, 1600°F., AIR COOLED, 1200°F., AIR COOLED. (B) 1800°F., AIR COOLED, 1600°F., FURNACE COOLED, 1200°F., AIR COOLED.

Properties	*(A)* 1800°F., Air Cooled 1600°F., Air Cooled 1200°F., Air Cooled		*(B)* 1800°F., Air Cooled 1600°F., Furnace Cooled 1200°F., Air Cooled	
Brinell Hardness No.	152	149	143	140
Yield Strength, lb. per sq. in.	57,800	57,300	53,300	51,200
Tensile Strength, lb. per sq. in.	79,200	79,100	76,100	75,400
Elongation in 2-In., per cent	30.0	30.8	29.5	30.0
Reduction of Area, per cent	59.7	61.4	53.6	53.0
Izod, ft. lb.	65.0		31.2	
Fracture	Fibrous		Granular	

greater improvement in ductility in steel No. 2667, containing no grain boundary non-metallics, than was produced in steel No. 2668, containing many such inclusions.

24. Neither of the two steels exhibited what could be considered satisfactory ductility in the normalized-and-drawn condition. The poor ductility of steel No. 2668 may properly be attributed to the presence of the chain-like, sulphide inclusions. Steel No. 2667

would have undoubtedly exhibited much higher values for reduction of area and the Izod test had it not been for the distribution of the Widmanstätten structure throughout the matrix as shown in Fig. 6B. The effect upon ductility of such a non-uniform distribution of one micro-constituent in a predominant or "matrix" structure will be discussed later. But regardless of this effect, the Izod test clearly indicated that the sulphide inclusions greatly handicapped the steel containing them. In the annealed condition, the ductility of both steels was again affected by a "network" distribution of pearlite in ferrite, but steel No. 2667 exhibited higher values for both reduction of area and the Izod test, proving again that the grain boundary inclusions were detrimental.

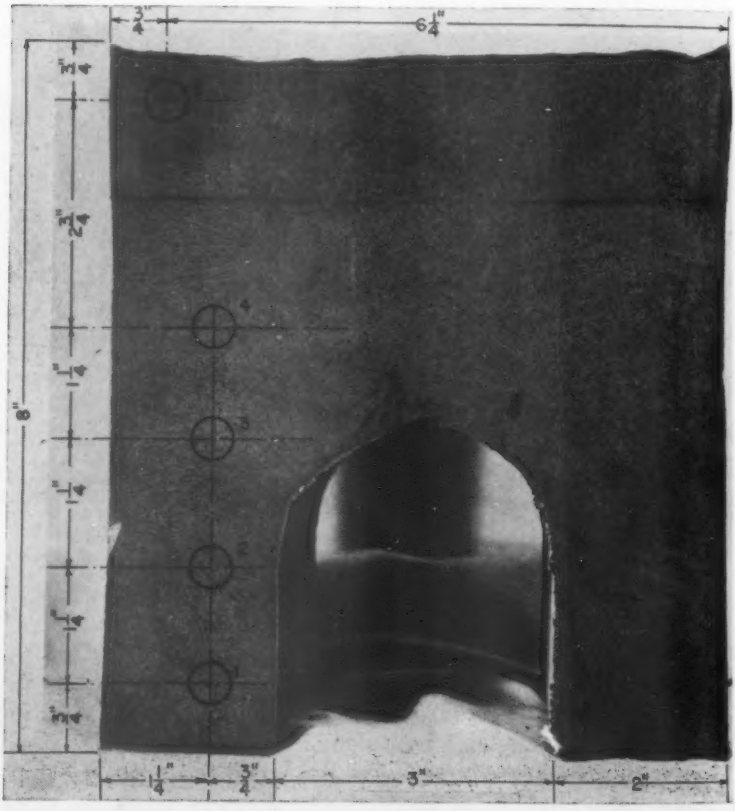


FIG. 10—MACRO-ETCHED CROSS SECTION OF NORMALIZED AND DRAWN MANGANESE-MOLYBDENUM STEEL CASTING SHOWING LOCATIONS FROM WHICH TENSION AND IZOD TEST SPECIMENS WERE MACHINED.

25. When the two steels were water quenched from 1600°F. and drawn at 1250°F., producing a hardness of 217 to 228 Brinell, the greatest differences in ductility were manifested. The steel containing the chain-like, sulphide inclusions exhibited considerably lower values for elongation, reduction of area, and Izod. Increasing the draw temperature and time at heat resulted in improvements in ductility in both steels. However, the Izod value for steel No. 2668 was still much below that of steel No. 2667.

26. The sulphide inclusions are soft yet brittle. It is difficult to believe that they can increase the resistance to flow; it seems more logical to assume that they reduce the resistance to fracture and thus decrease the amount of plastic deformation which can take place before cohesive failure occurs. Once localized fracture has occurred at the position of a chain of these inclusions, a sharp notch (crack) is formed which produces stress conditions more favorable to cohesive failure than to plastic deformation, so the reduction of area of a tensile specimen is greatly reduced and the energy absorbed in breaking a notched bar is low. The fractures of both specimens will be more or less brittle in character.

27. When the two steels were normalized-and-drawn or annealed, ferrite was the dominant micro-constituent which was the first to slip or deform plastically under the applied tensile stress. The flow stress was lower than when the steels were quenched from 1600°F. and drawn to a hardness of 217-228 Brinell. (The yield strength, or flow stress, of steel No. 2668, as measured by "the drop of beam method," was 85,300 lb. per sq. in. when quenched and drawn as compared with 46,200 lb. per sq. in. in the annealed condition.) Although the hardness was greater, the resistance to fracture in steel No. 2668 was still limited to some extent by the sulphide inclusions so the effect of the quench-and-draw treatment was to increase the resistance to flow with respect to the resistance to fracture. Plastic deformation, therefore, was lower. Steel No. 2667 evidenced a marked improvement in ductility when it was quenched and drawn to the higher hardness. Compared with the normalized-and-drawn structure, the uniform, drawn martensite possessed greater resistance to flow and greater resistance to fracture, but the resistance to fracture, in the absence of grain boundary non-metallic inclusions, was increased considerably more than the resistance to flow, so more plastic deformation occurred before cohesive failure.

28. The higher draw temperature and longer time at heat in

schedule No. 4 appreciably reduced the flow stress and the resistance to fracture in both steels, but apparently the flow stress was reduced more than the resistance to fracture so more plastic deformation could take place before fracture. Hence, greater values for elongation, reduction of area, and Izod tests were recorded. Comparing the two steels at 187 Brinell, the values obtained for elongation and reduction of area showed the effects of the sulphide inclusions in reducing ductility, but the differences in these values were not as pronounced as in the case of the Izod values. The latter test was a more sensitive criterion since the state of stress at the base of the notch was such that the maximum shear stress (that component of stress tending to produce plastic flow) developed was considerably less than the maximum normal stress (that component of stress tending to produce cohesive failure), and only a small amount of plastic deformation could occur before the normal stress became equal to the resistance to fracture, particularly when the resistance to fracture was low as in the case of steel No. 2668 containing the sulphide inclusions. The latter steel being otherwise composed of exactly the same micro-constituent as steel No. 2667 absorbed only 43 per cent as much energy in the Izod test.

29. A comparison of Figs. 6B and 6C indicates that steel No. 2667 had a somewhat higher hardenability than steel No. 2668, since the former contained greater amounts of the Widmanstätten structure than the latter when cooled at the same rate from 1600°F. Such a condition may be attributed to the fact that an increased sulphur content in steel No. 2668, resulting in the formation of larger amounts of manganese sulphide, reduced the total manganese content available for the stabilization of austenite.

30. Figure 6E illustrates the relationship between the grain boundary sulphide inclusions and the dendritic pattern formed during solidification. Note the presence of the sulphide inclusions in metal which froze at the interstices of austenite dendrites. This photomicrograph also indicates that these sulphide inclusions may serve to nucleate ferrite at temperatures above the nose of the S-curve, since they are completely surrounded by the ferrite phase even though they are situated in locations where the metal should be richest in alloying elements which tend to stabilize austenite.

SOLIDIFICATION PATTERN AND SEGREGATION OF ALLOYING ELEMENTS

31. The solidification of a medium carbon steel alloyed with

manganese and molybdenum may be considered as involving the transition from a liquid phase consisting of the liquid solution of these elements in iron to a solid solution of the same elements in gamma iron. When a solid solution results from the solidification of a liquid solution, crystallization takes place over a range of temperatures. The first crystals to freeze form the skeletons of dendrites and are low in concentration of alloying elements. As freezing progresses with continually decreasing temperature, the metal freezing on the original skeletons becomes more and more rich in alloying elements, until the last metal to freeze at the interstices of the dendrites contains the richest concentration of these elements.

32. If equilibrium were attained at every temperature level, diffusion of the alloying elements would take place in the solid state, as well as in the liquid state, and the final crystals would be uniform throughout with regard to the distribution of the dissolved elements. However, if sufficient time is not available for equilibrium to be attained, the concentration gradient between the skeleton of the dendrite and the last metal to freeze will persist. The formation of crystals, varying in composition from center to outside, is termed "coring," and the crystals themselves are frequently referred to as "cored" crystals.

33. When solidification is essentially instantaneous, as with extreme undercooling, very little segregation takes place since the growth of the crystals in a normal manner is prevented. As solidification takes place under conditions more closely approximating equilibrium, more segregation is effected. It is, therefore, logical to expect more segregation of alloying elements at the interior of the casting, or the location where the last molten metal solidifies, than at the exterior of the same casting. Minimum segregation occurs at both extremes of rates of solidification: (a) instantaneous solidification when diffusion in the liquid phase is suppressed, and (b) under ideal equilibrium when diffusion in the solid state is favored to such an extent that a uniform distribution of alloying elements results. In between these two extremes, extensive segregation takes place within the solidification range due to the rapid rates of diffusion in liquid metal and slow rates of diffusion in the solid state.

34. Very little diffusion of elements, such as manganese, chromium, and molybdenum, is effected in the solid state due to the slow rates of diffusion of these heavier elements in solid iron. The

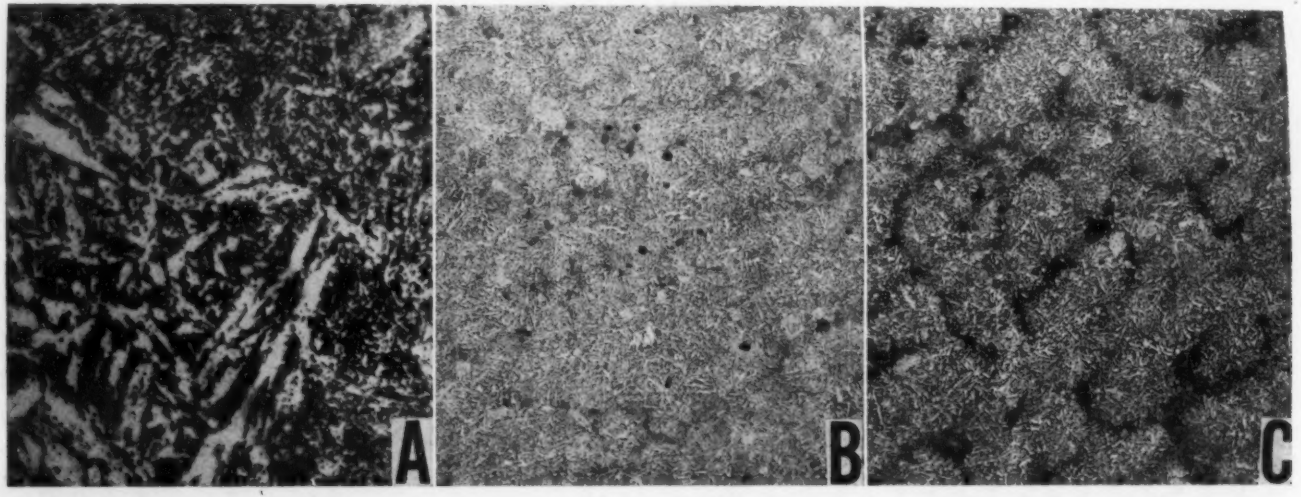
segregation persists unless a long homogenizing treatment at temperatures above 1950°F. is conducted to effect a more uniform distribution of the alloying elements by providing conditions favorable to their diffusion in solid iron. Carbon also segregates during solidification, but a high concentration gradient of this element is less apt to persist than one of manganese. It can be shown that, at 2200°F., carbon will diffuse through gamma iron 20,000 times as fast as manganese. At lower temperatures, this ratio is rapidly increased.

35. The size and shape of the crystals formed during the solidification of a metal depend upon the rate of solidification. The rate of solidification is dependent upon the rate of nucleation and the rate of growth of crystals, both of which are influenced by the rate of removal of heat from the molten metal. If the rate of removal of heat is rapid, the metal may be undercooled. Undercooling increases the speed at which nuclei are formed, although the rate of crystal growth is decreased. When a metal is undercooled as a result of chilling, such as casting against a metallic (permanent) mold, nucleation is rapid, and the structure consists of many fine, polyhedral crystals which are essentially equiaxed. As the rate of cooling is decreased, undercooling is less, and the rate of growth is favored with respect to the rate of nucleation. A rapid rate of growth associated with a slow rate of nucleation results in the formation of larger crystals. When solidification progresses rapidly from the wall of a mold with numerous crystals growing perpendicular to the surface, and the rate of growth is more rapid than the rate of nucleation, the result will be long, columnar dendrites as shown in Figs. 4 and 10.

36. When the rate of heat removal is reduced still further and conditions are such that undercooling is only slight, crystals form within the molten metal. The rate of nucleation is slow and growth is relatively rapid. The crystals are larger and more nearly equiaxed since they can grow for some time in comparative freedom before interference from other crystals restricts further growth. This structure formed in the interiors of castings is also illustrated in Figs. 4 and 10.

Effects of Solidification Pattern and Segregation on Mechanical Properties

37. In order to obtain a clear understanding of the effects of segregation and solidification pattern upon the mechanical properties of cast steel, it is considered expedient to review briefly the



A—2 Per Cent Nital X1000 *B—2 Per Cent Nital X50* *C—2 Per Cent Nital X50*

FIG. 11

BRINELL HARDNESS NUMBER	187	187
YIELD STRENGTH, LB. PER SQ. IN.	63,900	63,800
TENSILE STRENGTH, LB. PER SQ. IN.	96,300	96,300
ELONGATION IN 2-IN., PER CENT	23.5	22.0
REDUCTION OF AREA, PER CENT	54.1	39.4
IZOD, FT. LBS.	27	20.6

(REDUCED SLIGHTLY IN REPRODUCTION)

(A) DRAWN WIDMANSTATTEN AND MARTENSITIC STRUCTURES FOUND IN CASTING. ETCHED IN 2 PER CENT NITAL x1000. (B) AND (C) TYPICAL DISTRIBUTIONS OF THESE STRUCTURES REPRESENTATIVE OF TENSILE AND IZOD SPECIMENS FROM POSITIONS 1 AND 4 RESPECTIVELY OF KEEL CASTING SHOWN IN FIG. 10. ETCHED IN 2 PER CENT NITAL x50.

major principles concerned with the theory of the rates of reaction in steels at subcritical temperatures as originally developed by Bain and Davenport[6] in 1930 and amplified in more recent publications by these authors and others.

38. It is known that the products formed as a result of austenite decomposition vary markedly in appearance and physical properties. Austenite at subcritical temperatures decomposes to two phases, ferrite and carbide. It is the difference in distribution of these two phases that results in the formation of different micro-constituents. The micro-constituents formed, the modes of transformation by which they are formed, and the rates at which they are formed are dependent upon the temperature level at which austenite undergoes decomposition. In general, the rate of transformation of austenite at temperatures just below the A_1 temperature is very slow. The micro-constituents formed are ferrite and pearlite (in hypoeutectoid steels), and the hardness is low.

Table 2

RESULTS OF TENSILE AND IZOD TESTS ON SPECIMENS FROM CASTING SHOWN IN FIG. 10

Position of Specimen	*1*	*2*	*3*	*4*	*5*
Brinell Hardness No.	187	187	187	187	187
Yield Strength, lb. per sq. in.	63,900	63,800	63,900	63,800	63,700
Tensile Strength, lb. per sq. in.	96,300	96,100	96,300	96,300	96,100
Elongation, per cent	23.5	23.0	22.5	22.0	23.0
Reduction of Area, per cent	54.1	47.8	48.0	39.4	54.5
Izod	26.9	26.0	25.4	20.6	26.4
Microstructure	Fig. 11B			Fig. 11C	

Samples from block—Heat treated as cylinders.
¾-in. diameter, 4¾-in. long.
1650°F.—Water quenched.
1250°F.—2 hours.

Position of Specimen	*1*	*4*
Brinell Hardness No.	228	217
Yield Strength, lb. per sq. in.	88,600	85,800
Tensile Strength, lb. per sq. in.	111,700	107,800
Elongation, per cent	22	21.5
Reduction of Area, per cent	57	54.4

39. As the temperature of isothermal decomposition is lowered, the rates of reaction increase for plain carbon steels, the quantity of "free" ferrite is reduced, the interlamellar spacing of the pearlite diminishes, and, as a result, the hardness of the combination is increased. Ferrite, in these temperature ranges, is the first product of austenite decomposition. As this ferrite forms, the carbon diffuses to untransformed austenite which becomes smaller in quantity as ferrite rejection progresses. Eventually the carbon

content of the austenite reaches such a concentration that the precipitation of the carbide phase is initiated. The precipitated carbide particles nucleate the pearlite reaction, and, from this time, pearlite and ferrite form simultaneously until transformation is complete.

40. A maximum in the rates of reaction is attained at a temperature in the vicinity of 900 to 1000°F. At this temperature ferrite is no longer rejected *from* the austenite grain but is precipitated *within* the grain itself, and its precipitation is influenced by the crystallographic planes of the parent austenite. As this precipitation of ferrite proceeds along crystallographic planes, the carbide phase is concentrated between the plates and eventually precipitates more or less as chains of spheroids, if the reaction is allowed to go to completion.

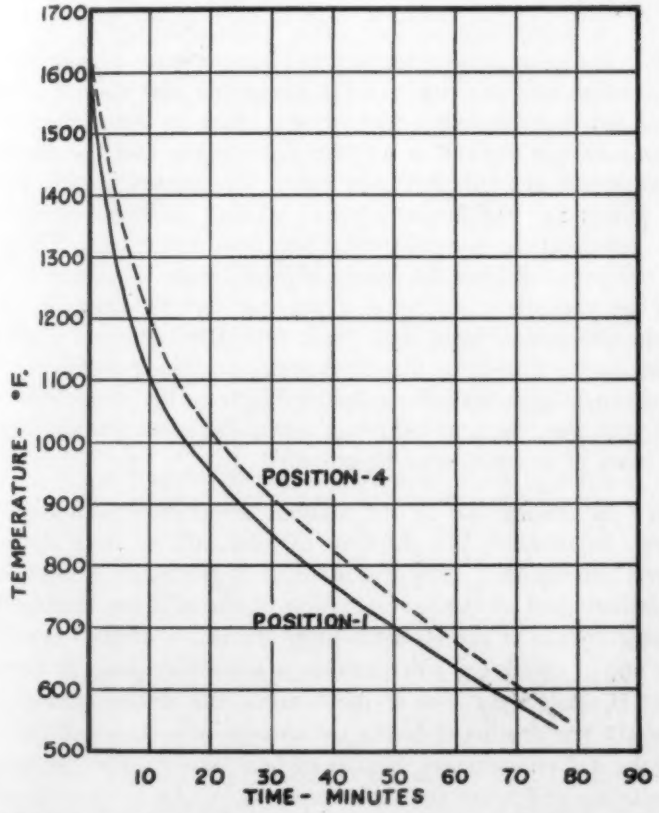


FIG. 12—COOLING CURVES OF CASTING SHOWN IN FIG. 10 AFTER NORMALIZING.

41. In the low and medium carbon ranges, 0.10 to 0.40 per cent carbon, the structure formed in the range of rapid rates of reaction is generally termed the Widmanstätten structure. (In steels with higher carbon contents the product is more dense and appears darker when etched. The name "Bainite" has been adopted for this latter structure.) At decreasing temperature levels, rates of reaction decrease, the product formed becomes finer, and the hardness increases. Lowering the temperature still further, another temperature is reached at which the rates of reaction abruptly attain a second maximum. This temperature depends upon the carbon content of the steel. The higher the carbon content is, the lower the temperature will be. The product formed at this low temperature is the hard, brittle martensite, and this temperature region is conveniently referred to as the *Ar"* transformation, or the "M-point."

42. The relationship between the temperature of austenite decomposition and the time for the beginning and ending of transformation is conveniently plotted on a chart on which the ordinate is temperature plotted on an arithmetic scale, and the abscissa is time plotted on a logarithmic scale. The curves drawn through the points for the beginning and ending of transformation at each temperature comprise what has been termed the "S-curve" for the steel. Figure 7A shows reproductions of S-curves which may be considered to have a bearing on the behavior of the manganese-molybdenum cast steel considered in this discussion. These curves cannot be directly applied to this investigation since the chemical analyses differ considerably from the composition dealt with, but some idea of the relationship between temperature and the rates of reaction may be obtained.

43. In general, all of the alloying elements except cobalt are known to increase the stability of austenite at, and above, the upper "maximum" (rate) or the nose of the S-curve. This stability is increased as the concentration of the alloying element is increased. Some of the elements alter the shape of the curve above this upper maximum and produce a secondary nose as shown in Fig. 7B. Below the nose of the S-curve, the carbon content is apparently the dominant factor influencing the shape of the curve and the *Ar"* temperature. Higher carbon contents decrease the rates of reaction and lower the *Ar"* temperature. An increase in carbon content up to the eutectoid concentration will also increase the time

required for the initiation and ending of the transformation between the A_1 temperature and the nose of the S-curve. An increase in the size of the austenite grains developed during austenitization lowers the rates of reaction above the nose.

44. Since the stability of austenite increases with the concentration of alloying elements, the distribution of these elements will greatly influence the distribution of micro-constituents in a heat treated cast steel. If all the alloying elements in a steel are uniformly distributed, the resulting structure of a section of the steel, cooled at any given rate from above the A_3 temperature, should be uniform regardless of the speed of quenching. If the cooling rate is faster than the critical cooling rate for the steel (that is, a cooling rate so fast that no transformation takes place at the nose, and all transformation takes place at, or below, the *Ar″* temperature), the whole structure will be martensite. If the critical cooling rate is not exceeded, some nose product (the Widmanstätten structure in manganese-molybdenum steel) will be uniformly scattered throughout a matrix of martensite.

45. However, if certain alloying elements are segregated, the

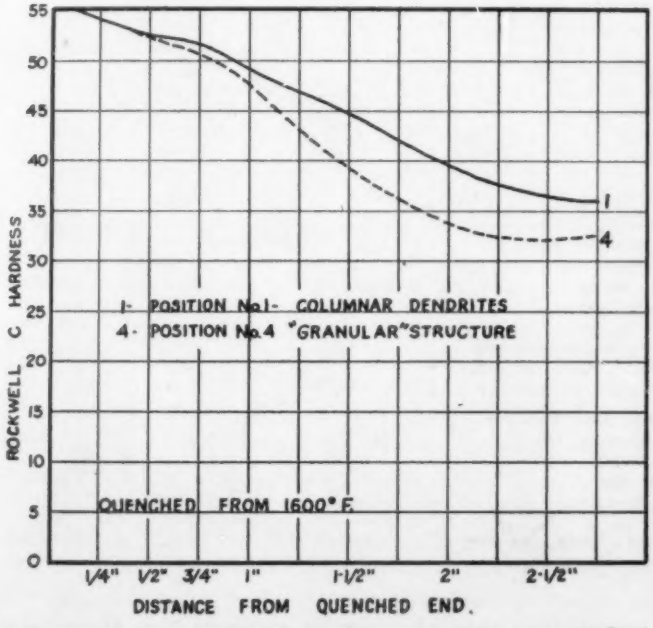


FIG. 13—RESULTS OF JOMINY END QUENCH HARDENABILITY TESTS PERFORMED ON SPECIMENS FROM POSITIONS ONE AND FOUR MACHINED FROM CASTING SHOWN IN FIG. 10

resulting structure will be different. First, the segregation of any element implies that some localities contain less than the average concentration and other localities contain more. Since some loca-

Table 3

TENSILE AND IZOD TEST DATA OBTAINED FROM SPECIMENS NORMALIZED, QUENCHED AND DRAWN AS INDICATED

NOTE: A.C. = Air Cooled. F.C. = Furnace Cooled. W.Q. = Water Quenched.

Chemical Analyses	*Plate A, per cent*		*Plate B, per cent*		*Plate C, per cent*	
Carbon	0.29		0.27		0.24	
Manganese	1.61		1.58		1.56	
Phosphorus	0.043		0.043		0.023	
Sulphur	0.024		0.033		0.019	
Silicon	0.47		0.46		0.41	
Molybdenum	0.44		0.44		0.39	
Heat Treatment						
Full sized plates	1800°F. 4 Hrs., A.C. 1600°F. 4 Hrs., W.Q. 1130°F. 4 Hrs., W.Q.		1800°F. 4 Hrs., A.C. 1600°F. 4 Hrs., W.Q. 1130°F. 4 Hrs., W.Q.		1850°F. 7 Hrs., A.C. 1650°F. 5 Hrs., W.Q. 1165°F. 3 Hrs., W.Q.	
Tensile and Izod						
(A) Edge of Plate						
Brinell Hardness No.	285	285	255	255	255	255
Yield Strength, lb. per sq. in.	116,600	117,700	101,800	103,400	109,900	114,400
Tensile Strength, lb. per sq. in.	141,900	143,000	125,400	127,000	125,100	129,800
Elongation in 2-in., per cent	16.0	17.5	17.5	15.5	18.0	17.8
Reduction of Area, per cent	42.8	49.5	46.9	38.2	52.5	48.9
Izod, ft. lb.	49.6		17.3		52.4	
(B) 12-in from Edge—Top						
Brinell Hardness No.	269		235		217	
Yield Strength, lb. per sq. in.	118,800		91,300		99,000	
Tensile Strength, lb. per sq. in.	140,000		112,200		155,000	
Elongation in 2-in., per cent	14.8		4.5		18.8	
Reduction of Area, per cent	31.2		7.4		51.4	
Izod, ft. lb.	—		—		—	
(C) 12-in. from Edge—Bottom						
Brinell Hardness No.	269		235		223	
Yield Strength, lb. per sq. in.	115,500		89,700		93,000	
Tensile Strength, lb. per sq. in.	134,000		111,100		109,500	
Elongation in 2-in., per cent	5.0		4.0		16.5	
Reduction of Area, per cent	11.5		5.8		52.5	
Izod, ft. lb.	—		—		—	

tions contain less than the average concentration of an alloying element, the nose of the over-all S-curve will be moved in the direc-

tion of decreased time and the critical cooling rate for the steel will be much faster than if the alloying element were uniformly distributed. Second, if the critical quenching rate for the steel is not exceeded, the localities low in concentration of alloying elements will transform at the nose of the S-curve, and the remain-

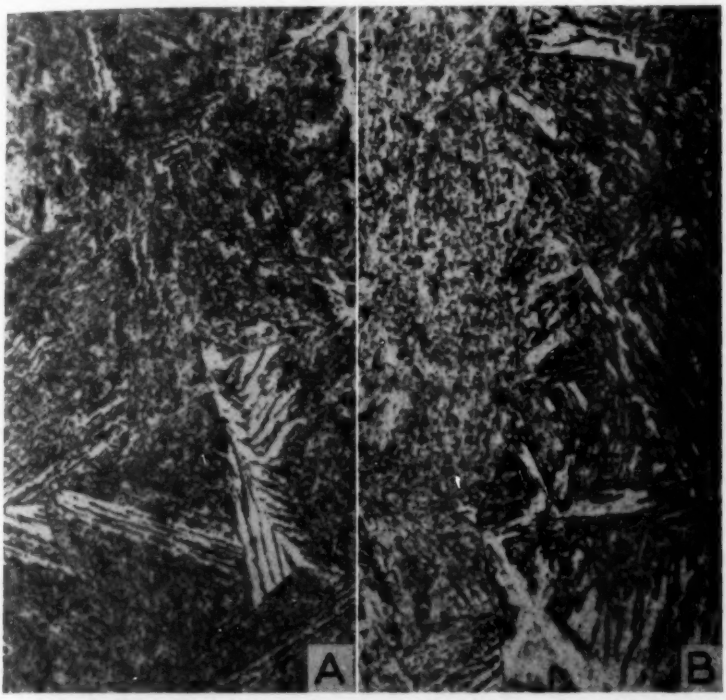


FIG. 14—SHOWING MICROSTRUCTURE OF SPECIMENS CUT FROM LARGE PLATE CASTING FROM AN ACID OPEN HEARTH HEAT. (A) EDGE OF PLATE A. (B) BOTTOM OF PLATE A, 12-IN. FROM EDGE. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION x1000.

ing austenite will transform to martensite at the Ar'' temperature. The distribution of the micro-constituents will, therefore, depend upon the distribution pattern of the segregated alloying element. If the critical cooling rate for the steel is exceeded, the resulting structure will be wholly martensitic.

46. Figure 7A illustrates the effects of the segregation of manganese upon the S-curve for a carbon-manganese steel (Society of Automotive Engineers T-1335). It will be noted that for the steel which was not homogenized, the transformation started sooner (in the localities containing less than the average concentration of manganese) and finished later (in the localities containing higher

than the average concentration of manganese) than it did in the homogenized steel in which the concentration of manganese was uniform throughout.

47. Upon slowly cooling a slightly segregated, hypoeutectoid steel, relatively low in alloy content, from above the critical temperature range, a temperature is reached at which ferrite starts to precipitate from the austenite. This precipitation will take place in the regions lowest in alloy content since the austenite of these regions is the least stable. At higher temperatures, the rate of nucleation is slow, and the rate of growth is comparatively rapid. The ferrite grains thus started in a region low in alloy content grow, rapidly expanding into locations whose concentration in alloying elements gradually increases. As the ferrite grains grow, the carbon builds up in the remaining austenite until most of it contains close to the eutectoid carbon content and the highest concentration of alloying elements. If the cooling rate is sufficiently slow, a temperature will finally be attained at which pearlite is nucleated and the remaining austenite will transform to pearlite. The resulting structure will consist of ferrite in regions low in alloy content and pearlite in regions high in alloy content, and the segregation pattern of the alloying elements will be clearly defined.

48. If the same steel is cooled at a somewhat faster rate to a temperature at which the rate of nucleation is rapid, ferrite may start to grow in all locations simultaneously and a uniform distribution of ferrite and pearlite will be developed. Figures 8 and 9 show the microstructures developed in two steels by varying slightly the rates of cooling from an austenitizing temperature of 1600°F.

49. The purpose of this part of the discussion is to show that the distribution of micro-constituents (as affected by the segregation of alloying elements) affects the ductility of a cast steel. The first evidence to support this contention is presented in Figs. 8 and 9 and the accompanying tabulated properties. In each case, castings were produced in the laboratory. Thirty lb. heats of steel were melted down and alloyed in an acid-lined induction furnace. Each heat was killed with 0.08 per cent aluminum and was poured into a double keel block mold. The casting consisted of two parallel bars one-in. square and 11-in. long, one-in. apart. The remainder of the metal comprised the head which was 3-in. wide at the top of the keel bars and flared out to 4½-in. at a dis-

tance approximately 3-in. above the tops of the bars. The keel bars were sawed from the full casting, and the designated heat treatments were conducted on 1-in. square sections. Tensile test specimens and Izod specimens were machined from heat-treated sections. It will be noted that the reduction of area is less for the annealed bar than for the normalized bar in each case. The greatest difference in ductility, however, is revealed by the Izod test. The fractures for the normalized bars were ductile or "fibrous," whereas the fractures of the annealed samples were distinctly brittle and "granular."

50. In both the annealed and the normalized samples, the micro-constituents were ferrite and pearlite. In the normalized samples, these two micro-constituents were uniformly distributed throughout the steel. In the annealed samples, the ferrite had precipitated at the "cores" of the dendrites and expanded until the final austenite to transform to pearlite had assumed the segregation pattern formed during solidification. The uniform distribution of pearlite in the normalized bars proves that there was no significant segregation of carbon in the austenite developed at 1600°F.

51. The harder pearlite, distributed as a network in the annealed specimens, restricted the plastic deformation of the soft, ductile, ferrite matrix, thereby increasing the resistance to flow. This increase in resistance to flow was detected by a slight decrease in the value for the reduction of area as measured in the tension test. However, it had a pronounced effect upon the behavior of the steel when subjected to the notched-bar test, reducing the energy absorbed in breaking the Izod specimen to less than half the value recorded for the normalized specimens.

52. The next evidence presented is concerned with data obtained from tensile and Izod specimens machined from various locations in a large commercial casting of manganese-molybdenum steel which had been normalized and drawn. Figure 10 shows a macro-etched cross section of the casting which was approximately 15-in. long and weighed 163 lb. as cast. Standard 2-in. gauge length tension test specimens (ASTM-E8-42) and Izod specimens with the standard cross section and standard notch (E23-41T) were machined from the locations indicated. The results of tests run on these specimens are presented in Table 2. Figure 11A illustrates the drawn Widmanstätten structure and the drawn martensitic structure found in the normalized and drawn block. Figures 11B and 11C show typical distributions

of these micro-constituents representative of tensile specimens exhibiting high and low values for the reduction of area. These structures also represent high and low Izod values. The network pattern consisting of drawn martensite is associated with the lower values for the reduction of area and for the Izod test, whereas the higher values are found in specimens which exhibit a uniform Widmanstätten structure.

53. When the casting was normalized, thermocouples were inserted into holes drilled adjacent to the No. 1 and No. 4 positions. These thermocouples were connected to an automatic recorder and the time-temperature curves for both positions were obtained. The cooling curves are presented in Fig. 12. Note how closely they

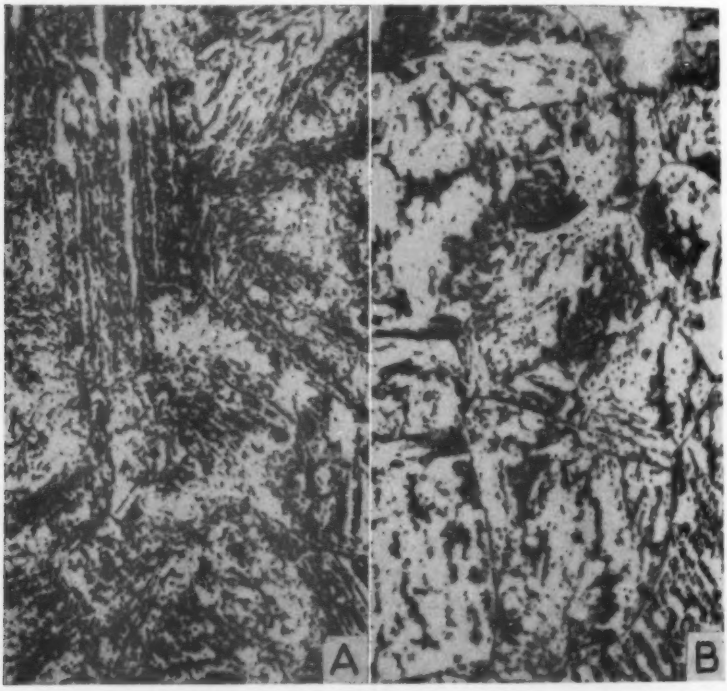


FIG. 15—SHOWING MICROSTRUCTURE OF SPECIMENS CUT FROM LARGE PLATE CASTING FROM AN ACID ELECTRIC HEAT. (A) EDGE OF PLATE B. (B) BOTTOM OF PLATE B, 12-IN. FROM EDGE. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION x1000.

parallel one another and that the rates of cooling through the region 1080 to 940°F. are practically identical. The difference in final microstructure may be explained on the basis of the segregation of the alloying elements formed during solidification. The

steel solidifying in the keel froze much more rapidly than the metal in position No. 4. It was less segregated and the differences between the concentrations of alloying elements from the cores of the dendrites to the interstices were only slight. The cooling rate was slower than the critical cooling rate for every microscopic locality, and the whole section transformed to the Widmanstätten structure between 900 and 1050°F.

54. The metal in position No. 4 froze more slowly owing to the greater quantity of metal and the greater heat content. As a result there was considerable segregation. The alloy concentration in the interstices of the dendrites was appreciably above the average and the alloy concentration in the cores of the dendrites was considerably below average. The cooling rate of the steel was slower than the critical cooling rate for the less rich regions but it was faster than the critical cooling rate for the regions richer in alloy content which lay at the interstices of the dendrites. The less rich austenite transformed to the Widmanstätten structure in the range of 900 to 1050°F., but the austenite higher in alloy content remained stable down to the Ar'' where it transformed to martensite. When the block was drawn at 1250°F., the Widmanstätten structure was practically unchanged except for increased spheroidization of the carbide phase. Martensite changed to "spheroidite," and its hardness was lowered. The composite structure, therefore, consisted of 2 different structures, and one of these, the drawn martensite, formed a network pattern.

55. In order to prove that the network pattern of one constituent enclosing regions composed of a second constituent was responsible for the poor ductility, as compared to that obtained in specimens exhibiting a uniform structure of practically a single constituent, rather than an increase in porosity or in the quantity of non-metallic inclusions, 2 tensile specimen blanks were machined from positions Nos. 1 and 4 in the block. These blanks were ¾-in. diameter x 4¾-in. long. They were placed in a furnace at 1650°F., held there one hour and water quenched. They were subsequently drawn at 1250°F. for 2 hours. The results of these tests are presented in Table 2. Although the hardness of the specimen from position No. 4 was slightly lower than the specimen from position No. 1, the 2 compared favorably and the difference in ductility was slight as compared to the difference in the normalized specimens. The faster rate of cooling from the austenitizing temperature was sufficient to exceed the critical cooling rates of all

parts of the specimens and uniform microstructures of martensite were obtained after quenching. Drawing at 1250°F. served to convert the martensite to spheroidite, and the same uniformity prevailed.

56. Jominy end quench hardenability specimens were prepared

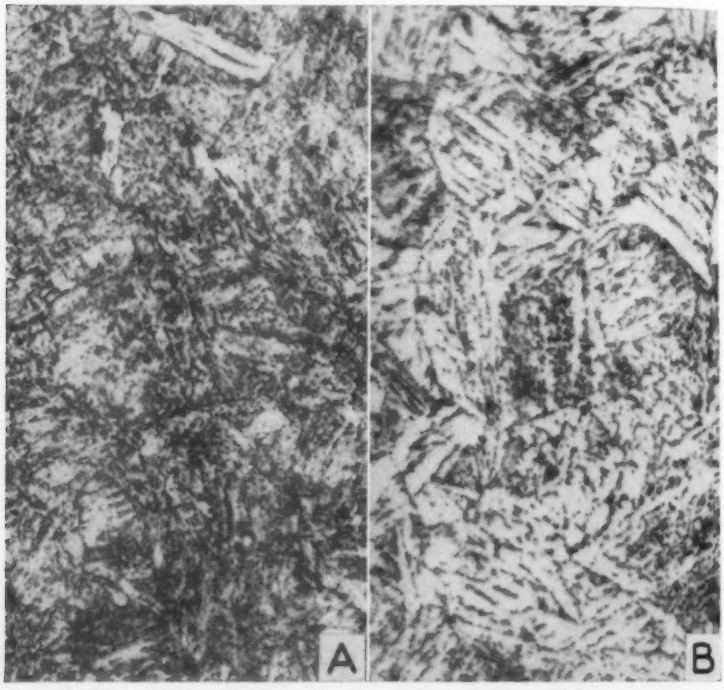


FIG. 16—SHOWING MICROSTRUCTURE OF SPECIMENS CUT FROM LARGE PLATE CASTING FROM A BASIC ELECTRIC HEAT. (A) EDGE OF PLATE C. (B) TOP OF PLATE C, 12-IN. FROM EDGE. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION X1000.

from positions Nos. 1 and 4. These were quenched from 1600°F. The results of these hardenability tests are presented in Fig. 13. It is clearly shown that the segregation of the alloying elements decreases hardenability.

Plate Castings

57. Large plate castings of manganese-molybdenum steel exhibit similar tendencies. Plates 1½- to 2-in. thick which have been water quenched and drawn have been found to possess higher ductility at one surface than at the other, and both of these surfaces may possess properties different from those of the metal at

the edges of the plate. Table 3 presents tensile and Izod test data obtained from specimens machined from various locations of full 1½- to 1⅝-in. plates which were normalized, quenched, and drawn as indicated.

58. It will be noted that in every case the hardness for the "edge" specimens was greater than for the specimens cut from the plate at a distance 12-in. from the edge. The tensile strength was lower at the bottom surface of each of the acid plates than at the top. The lower ductility exhibited in the top and bottom positions 12-in. from the edge can be accounted for partly by the porosity due to shrinkage, as shown in Fig. 5, A, B and C. But this was not necessarily the only cause. Metallographic examination of specimens cut from the tensile and Izod test bars revealed a distinct difference in microstructure between the top and bottom positions. In plate A, the microstructure of the edge sample was almost uniformly drawn martensite. There were a few evidences of the Widmanstätten structure as shown in Fig. 14A. The "top" and "bottom" specimens showed an increase in the quantity of Widmanstätten structure.

59. In plate B, the differences existing between the edge section and the top and bottom positions 12-in. away from the edge were even greater. Figure 15A shows the microstructure of the edge section, and Fig. 15B shows the microstructure of the tensile specimen cut from the bottom of the plate 12-in. from the edge. The microstructure of the top position was intermediate between these two. Plate C indicated a similar condition, except in this case the top position showed the greatest amount of high temperature products of austenite decomposition followed by the "bottom" position, and the edge section was almost completely drawn martensite as shown in Fig. 16, A and B.

60. The difference in microstructure between the edge section and portions 12-in. from the edge in a water quenched 1⅝-in. plate might be explained on the basis that the rate of cooling of the metal at the edge would be considerably greater than that of the metal 12-in. away from the edge. However, this does not explain why there should be a difference in structure between the top and bottom of a plate which was water quenched in a large tank of water with the top and bottom plane surfaces in a vertical direction. Although hardness tests, after drawing, revealed little difference between the two, the presence of more Widmanstätten structure at one surface than at the other indicated a difference in

hardenability between the two surfaces. To check this observation, Jominy end quench hardenability specimens were prepared from the plates in such a manner that the conventional, ground hardness "flats" represented parts of the plates approximately 12-in. from the edges and 0.055- to 0.085-in. from the top surface, 0.60- to 0.70-in. from the top surface, 0.60- to 0.70-in. from the bottom surface and 0.055- to 0.085-in. from the bottom surface. The results of these tests are presented in Figs. 17, 18 and 19. These data definitely proved that there was a difference in hardenability between the bottom and top surfaces of the cast plate. The macrostructures of these plates, correlated with the hardenability data, indicated a consistency. The columnar, dendritic structure in each case possessed the higher hardenability.

61. In order to determine more clearly the differences in solidification pattern and the segregation of alloying elements in the three plates, small samples representative of the "top" and "bottom" positions were heated to 1650°F. and cooled to 800°F. at 25°F. per hour. Photomicrographs of these samples at 50 diameters are presented with the hardenability curves in Figs. 17, 18 and 19.

62. To ascertain if differences in chemical analysis between top and bottom might be the cause of the variations in hardenability, carbon, manganese and molybdenum contents were determined on samples milled from the plates from 0.070- to 0.090-in. from each surface. The following results were obtained:

	Over-all or Average, per cent	*Top, per cent*	*Bottom, per cent*
Plate A			
Carbon	0.29	0.25	0.27
Manganese	1.61	1.61	1.63
Molybdenum	0.46	0.45	0.45
Plate B			
Carbon	0.28	0.26	0.27
Manganese	1.53	1.58	1.57
Molybdenum	0.45	0.43	0.42
Plate C			
Carbon	0.24	0.25	0.25
Manganese	1.56	1.57	1.57
Molybdenum	0.39	0.39	0.39

The differences in chemical analysis between top and bottom surfaces are not sufficient to account for the differences in hardenability.

63. Correlating the microstructures with the ductility of the steels, it will be noted that the specimens, which were most nearly uniform, drawn martensite, possessed the higher ductility. The edge section of plate B contained considerably greater quantities

Table 4

RESULTS OF SPECIAL LABORATORY EXPERIMENTS ON PLATES A, B AND C

Heat Treated as Bars One-in. Diameter from Sound-Edge Sections
NOTE: A.C. = Air Cooled. F.C. = Furnace Cooled.
W.Q. = Water Quenched.

		—A—		—B—		—C—	
(A)	*1650°F. 2 Hrs., W.Q.* *1275°F. 2 Hrs., W.Q.*						
	Brinell Hardness No. ...	197	197	197	197	207	207
	Yield Strength, lb. per sq. in.	79,200	78,700	78,700	78,100	92,400	92,400
	Tensile Strength, lb. per sq. in.	101,300	101,200	102,300	100,900	103,800	104,000
	Elongation in 2-in., per cent	25.8	25.0	23.0	26.5	23.0	25.2
	Reduction of Area, per cent	52.6	55.2	45.5	56.2	53.3	58.6
	Izod, ft. lb.	71.2		—		62.9	
(B)	*1650°F. 2 Hrs., F.C.*						
	Brinell Hardness No. ...	207	207	192	197	207	207
	Yield Strength, lb. per sq. in.	—	—	—	—	—	—
	Tensile Strength, lb. per sq. in.	111,600	111,100	103,400	106,800	112,800	113,200
	Elongation in 2-in., per cent	15.5	12.8	12.5	12.5	15.0	14.8
	Reduction of Area, per cent	18.8	14.1	14.9	12.3	18.8	20.2
	Izod, ft. lb.	5.2		—		9.2	
(C)	*1650°F. 2 Hrs., A.C.* *1250°F. 2 Hrs., W.Q.*						
	Brinell Hardness No. ...	197				197	197
	Yield Strength, lb. per sq. in.	68,200				71,000	71,500
	Tensile Strength, lb. per sq. in.	101,700				101,100	99,900
	Elongation in 2-in., per cent	21.0				25.0	22.2
	Reduction of Area, per cent	45.2				57.0	47.5
	Izod, ft. lb.	35.8				69.5	

of higher temperature products of austenite decomposition than the edge section of plate A. With a lower hardness, plate B possessed elongation and reduction values comparable with plate A, but the more sensitive Izod test readily detected the difference in ductility between the two structures. The hardenability curves show that the best hardenability of plate B (the top of the plate)

was about comparable with the lowest hardenability of plate A (the bottom section).

64. Plate C with its lower carbon content and reduced hardenability behaved in a different manner. When the critical cooling rate of this plate was not exceeded, the structure formed was almost uniformly the Widmanstätten constituent which alone exhibited excellent ductility as measured by the tensile test.

Effects of Cooling Rates upon Microstructures and Mechanical Properties

65. In order to study the effects of variations in cooling rates upon the microstructures and mechanical properties of the steels of these particular plates, some experiments were conducted with sound edge material. Sections one-in. in diameter were normalized and drawn, water quenched and drawn, and annealed. Tensile and Izod tests were run on these heat treated cylinders. The results of these tests are presented in Table 3. The hardnesses for all specimens were within a fairly narrow range. When fully quenched and subsequently drawn to the same hardness, all 3 steels exhibited comparable ductility as measured by the tensile test. Steel A exhibited a higher value for the Izod test than did steel C.

66. When specimens from the 3 heats were furnace cooled at 50°F. per hour from 1650°F., the ductility was uniformly poor as measured by either the tension test or the Izod test. Figures 20 and 21 illustrate the microstructures of tensile specimens from plates A and C in the quenched and drawn condition and after annealing. Both treatments produced microstructures in plate A which showed solidification patterns. Micro-hardness tests were conducted, using a diamond ground to the Vickers specification and a load of 14.8 gr., to determine the variations in hardness from one constituent to the other. In the quenched and drawn condition the greatest variation in hardness was from 235 to 310 Diamond Pyramid hardness numbers. In the annealed condition the maximum variation was from 181 to 474. The ductility in the latter case was very low. Figure 22 illustrates the fractures of the tensile specimens.

67. It is apparent that the harder constituents, martensite and Widmanstätten, resist slip, and, due to the distribution of these constituents, plastic deformation of the soft, ductile ferrite is restricted to a small quantity before its cohesive limit is attained. The fracture is brittle even under the almost ideal conditions of the tension test. Although the quenched-and-drawn specimens

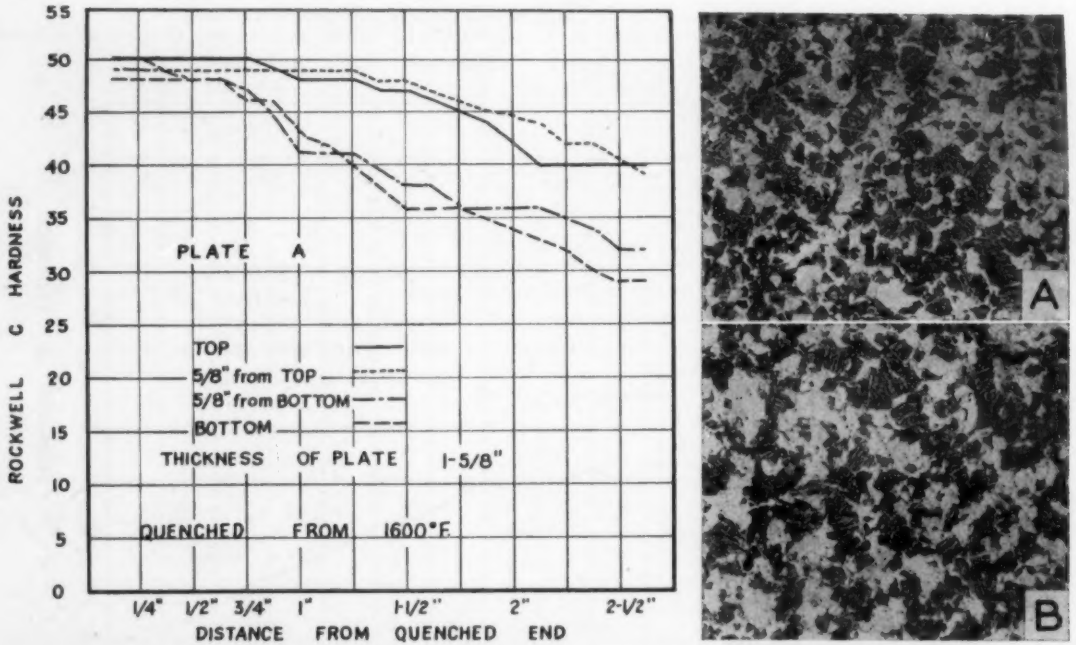


FIG. 17—SHOWING RESULTS OF JOMINY END QUENCH HARDENABILITY TEST PERFORMED ON SPECIMENS TAKEN FROM PLATE A. PHOTOMICROGRAPHS (x50) AT RIGHT REPRESENT ANNEALED SPECIMENS FROM (A) TOP AND (B) BOTTOM POSITIONS OF PLATE A.

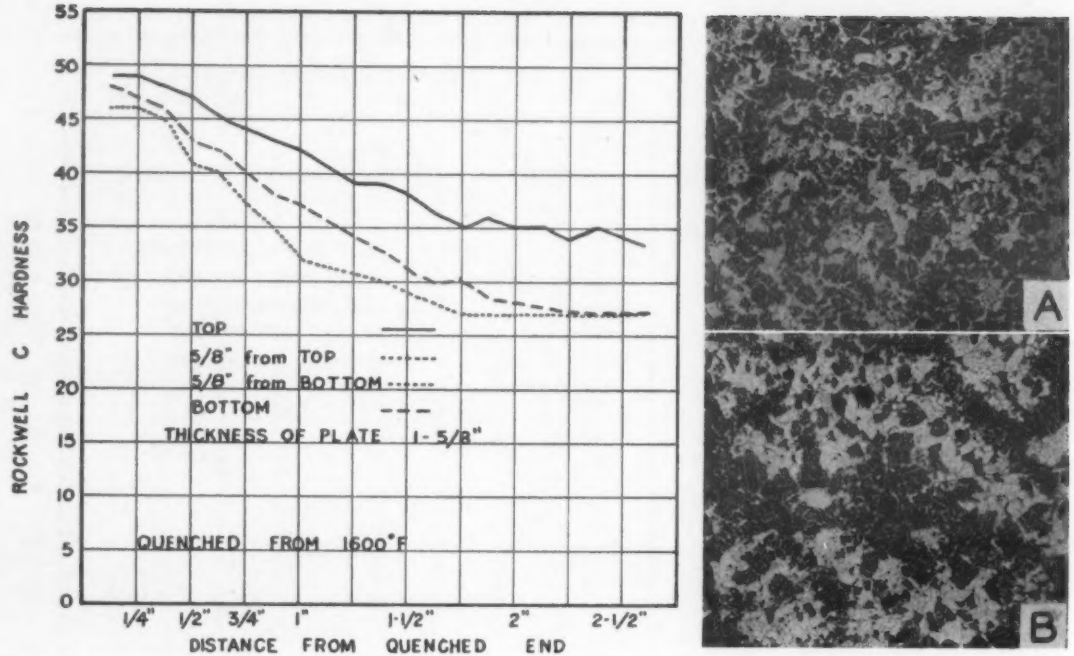


FIG. 18—SHOWING RESULTS OF JOMINY END QUENCH HARDENABILITY TESTS PERFORMED ON SPECIMENS TAKEN FROM PLATE B. PHOTOMICROGRAPHS (x50) AT RIGHT REPRESENT ANNEALED SPECIMENS FROM (A) TOP AND (B) BOTTOM POSITIONS OF PLATE B.

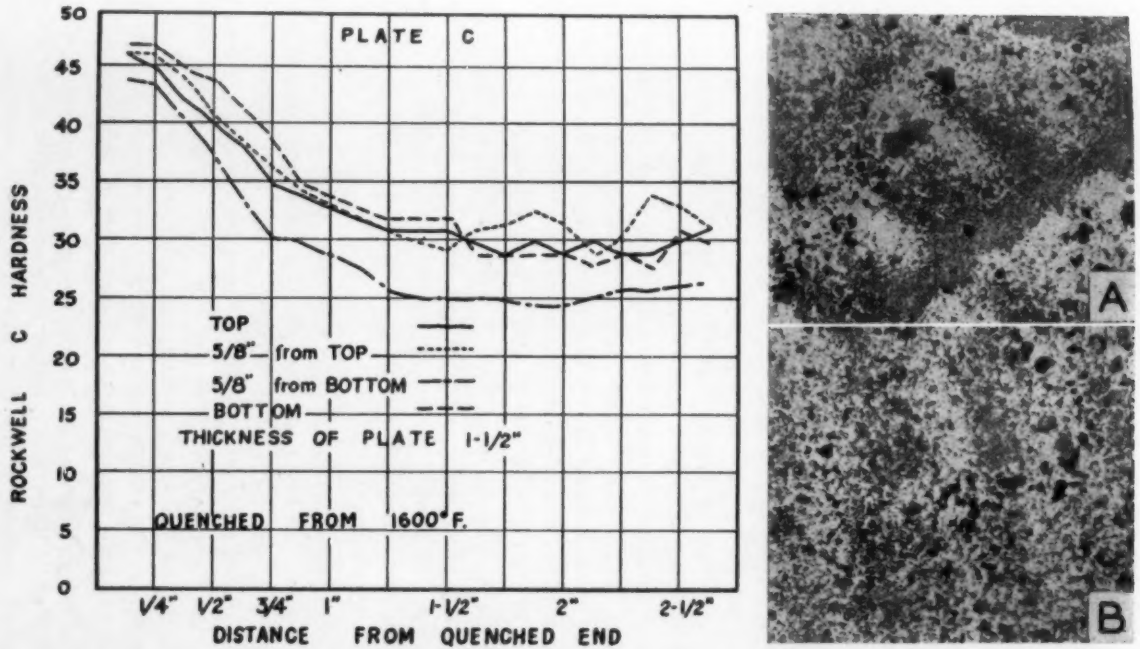


FIG. 19—SHOWING RESULTS OF JOMINY END QUENCH HARDENABILITY TESTS PERFORMED ON SPECIMENS TAKEN FROM PLATE C. PHOTOMICROGRAPHS (x50) AT RIGHT REPRESENT ANNEALED SPECIMENS FROM (A) TOP AND (B) BOTTOM POSITIONS OF PLATE C.

and the normalized-and-drawn specimens exhibited definite yield points, as indicated by the "drop of beam" and by the "dividers method" (ASTM-E8-42), no indication of "yield" by either method was detected in the tension tests conducted on the annealed specimens. Since the notch and loading conditions of the Izod test increases the ratio of the maximum normal stress of the maximum shear stress the ductility of the notched bars of the annealed steels was exceptionally low.

68. Upon slowly cooling the sample of steel from 1650°F., ferrite had been the first product to form from the decomposition of austenite. This ferrite formed in the regions less rich in alloying elements. As cooling progressed the ferrite grains grew in size and the carbon migrated to the austenite which remained in the regions rich in alloy content, thus increasing its carbon concentration. By the time the temperature of the steel reached the nose of the curve, this remaining austenite had become so stabilized that only a portion of it transformed to the Widmanstätten structure and the remainder of it existed untransformed until the steel reached the *Ar"* temperature where martensite resulted from its decomposition. While the over-all hardness was almost the same as that of the quenched-and-drawn sample, the characteristics of the micro-constituents and their distributions resulted in considerable difference in ductility. Plates B and C behaved similarly.

69. When specimens from plate A were normalized, the ductility was better than when annealed but less than when quenched and drawn. However, when specimens from plate C were normalized, their ductility was as good as that of the quenched-and-drawn specimens.

70. These experiments indicate why plate C, as heat treated in the full section, exhibited uniform ductility throughout, although the microstructure varied appreciably. They also explain why plate B exhibited such poor ductility throughout, even at the edge section. Its hardenability was so low that even when water quenched in the full-sized section, the edge was composed of a structure which was equivalent to a normalized section of plate A, and the normalized microstructure of cast steel of this composition exhibited poor ductility.

71. Figure 23 illustrates a rather unusual example of the effect of a network pattern on the ductility of a tensile specimen. The specimen was free from porosity and grain boundary inclusions, yet its ductility was low as measured by the reduction of area. The

wrinkled surface structure usually associated with metals which work harden (such as austenitic Hadfield's manganese steel) was in this case produced by a network of hard material in a softer, more ductile matrix. The microstructure, when examined at 1000 diameters, indicated that the network was chiefly a more dense population of carbide spheroids than existed in the predominant, or matrix, structure. Apparently some segregation of carbon prevailed in the austenite prior to quenching. This is another example of a harder network material restricting the plastic deformation of a softer matrix, thereby raising the flow stress with respect to the cohesive limit.

TEMPER BRITTLENESS

72. No discussion of the factors influencing the ductility of cast steel could be considered complete without consideration being given to the factor of "temper brittleness." The term "temper brittleness" applies to the phenomenon exhibited by most steels, some more than others, in which higher ductility is realized when the steel is quenched in water following a high temperature draw (1000°F. to 1300°F.) than can be obtained if the steel is slowly cooled from the same temperature. Whereas this characteristic is very pronounced in some steels, being readily detected by the Izod test at room temperature, in other steels a more sensitive criterion is required to detect its existence. The Charpy-temperature curve was used in the following experiments to show that some cast steels are susceptible to temper brittleness and that a water quench following the draw is advantageous toward obtaining the best performance of the steel.

73. The tests for this part of the investigation were conducted on 8 coupons of commercially cast manganese-molybdenum steel, representative of 2 heats which had been produced in basic electric furnaces. Each coupon was 2-in. x 2¼-in. x 8-in. and had been flame cut from a larger production casting. Five of the 6 sides were "as cast" surfaces, while the sixth side, a 2- x 8-in. face, was produced by the cutting torch. The final deoxidation of both heats of steel had been accomplished by the use of ferro-carbon-titanium. The regular commercial heat treatment applied to the larger production castings represented by the coupons was as follows:

(a) Eight-hour soak at 1800 to 1850°F., followed by an air cool.

(b) Three-hour soak at 1600 to 1625°F., followed by a water quench.

(c) Six-hour soak at 1190 to 1210°F., followed by a water quench.

74. The experiments described below were designed to indicate the value of the 1800 to 1850°F. soak, prior to the regular quench-and-draw treatment, and to evaluate the water quench following the draw. Four different heat treating cycles were applied to each heat, each block receiving a different treatment, as follows:

Heat Treatments

Heat Treatment No. 1—One block each heat
(a) 1850°F., 8 hours—air cooled to room temperature
(b) 1625°F., 3 hours—water quenched to room temperature
(c) 1200°F., 6 hours—water quenched to room temperature

Heat Treatment No. 2—One block each heat
(a) 1850°F., 8 hours—air cooled to room temperature
(b) 1625°F., 3 hours—water quenched to room temperature
(c) 1200°F., 6 hours—furnace cooled to room temperature

Heat Treatment No. 3—One block each heat
(a) 1625°F., 3 hours—water quenched to room temperature
(b) 1200°F., 6 hours—water quenched to room temperature

Heat Treatment No. 4—One block each heat
(a) 1625°F., 3 hours—water quenched to room temperature
(b) 1200°F., 6 hours—furnace cooled to room temperature

NOTE: In every case the 2-in. x 2¼-in. x 8-in. coupon was placed in a large electric furnace at the designated temperature and held the specified length of time.

Tests

75. One cross section slab, ¼-in. thick, was cut from each block 2-in. from one of the 2-in. x 2¼-in. end faces. These slabs were surface ground and etched for 45 min. in boiling 1:1 hydrochloric acid solution. All of the castings were found to be sound throughout. The heat treatments to which the cast coupons had been subjected had no effect on the macrostructures of the etched cross sections. All castings from one heat had one characteristic macrostructure, regardless of heat treatment. Figure 24 illustrates the macrostructures exhibited by the castings from the 2 heats.

76. Two standard 2-in. gauge length tension test specimens (ASTM-E8-36) were machined from the bottom (in Fig. 24) of each heat treated coupon as near the middle as possible. The speci-

mens were tested to destruction in an hydraulic testing machine.

77. Charpy key-hole notched specimens (ASM *Metals Handbook*, 1939 edition, p. 673, Fig. 2) were machined from remaining portions of each block. The 2-in. dimensions of the Charpy specimens were perpendicular to the sides of the coupons. Three specimens of each coupon were broken at the following °*F.* temperatures: 125, 73, 0, –25, –50, –85. Where a sufficient number of specimens was available, some were also broken at 175°F. Results

Table 5

RESULTS OF TENSION AND CHARPY TESTS ON SPECIMENS FROM HEAT NO. 164

NOTE: A.C. = Air Cooled. F.C. = Furnace Cooled. W.Q. = Water Quenched.

Chemical Analysis, per cent:

Carbon	.29
Manganese	1.66
Silicon	.47
Molybdenum	.41
Phosphorus	.007
Sulphur	.010

Heat Treatment:	*1*		*2*		*3*		*4*	
	1850°F., A.C. 1625°F., W.Q. 1200°F., W.Q.		1850°F., A.C. 1625°F., W.Q. 1200°F., F.C.		1625°F., W.Q. 1200°F., W.Q.		1625°F., W.Q. 1200°F., F.C.	
Tensile Properties:								
Brinell Hardness No.	212	212	212	212	223	223	220	220
Yield Point, lb. per sq. in.	89,100	87,500	84,200	84,900	94,600	93,500	90,200	91,300
Tensile Strength, lb. per sq. in.	107,300	106,700	106,400	106,300	111,100	111,100	109,600	110,600
Elongation in 2-in., per cent	23.0	22.4	22.4	22.6	20.6	19.2	21.0	22.0
Reduction of Area, per cent	54.9	54.7	54.7	55.9	53.8	35.4*	50.0	53.8

Charpy Impact, ft. lb. (Average):

°*F.*				
175	47.0	47.1	—	39.6
125	47.5	41.1	45.6	39.7
73	46.2	42.2	42.7	37.9
0	41.5	35.0	40.8	30.8
-25	40.6	29.6	36.6	26.5
-50	39.4	24.5	29.7	17.6
-85	23.9	16.4	24.5	18.0

* Shrinkage cavity found at fracture of test bar.

of the tension tests and average results for the Charpy tests are presented in Tables 5 and 6. The Charpy test data plotted in chart form are presented in Fig. 25.

Table 6

RESULTS OF TENSION AND CHARPY TESTS ON SPECIMENS FROM HEAT NO. 172

NOTE: A.C. = Air Cooled. F.C. = Furnace Cooled.
W.Q. = Water Quenched.

Chemical Analysis, per cent:

Carbon	.28
Manganese	1.62
Silicon	.42
Molybdenum	.37
Phosphorus	.007
Sulphur	.012

Heat Treatment:	*1*		*2*		*3*		*4*	
	1850°F., A.C. 1625°F., W.Q. 1200°F., W.Q.		1850°F., A.C. 1625°F., W.Q. 1200°F., F.C.		1625°F., W.Q. 1200°F., W.Q.		1625°F., W.Q. 1200°F., F.C.	
Tensile Properties:								
Brinell Hardness No.	217	217	212	212	223	223	225	225
Yield Point, lb. per sq. in.	88,600	88,700	84,500	84,600	95,700	99,000	94,100	94,400
Tensile Strength, lb. per sq. in.	108,400	108,800	105,800	106,600	112,200	112,800	111,700	112,200
Elongation in 2-in., per cent	23.5	22.4	23.2	22.5	22.4	21.0	22.0	22.5
Reduction of Area, per cent	60.6	58.6	57.8	55.7	56.0	56.0	54.4	47.4

Charpy Impact, ft. lb. (Average):

°F.				
175	44.0	—	—	—
125	45.3	—	42.7	39.7
73	50.0	42.8	42.8	36.6
0	43.1	28.1	36.8	26.9
–25	36.0	24.2	33.0	25.0
–50	29.9	18.9	29.2	15.8
–85	27.8	9.2	19.9	7.1

Special Tests on "End" Specimens

Heat Treatment Schedule	*Temperature of Test °F.*	*Single Break End Specimen*	*Average of 2 or More Breaks Normal Specimens (See above values)*
1	–50	54.4	29.9
1	–85	43.7	27.8
2	0	41.2	28.1
2	–85	34.4	9.2
3	–85	30.7	19.9
4	–50	27.1	15.8

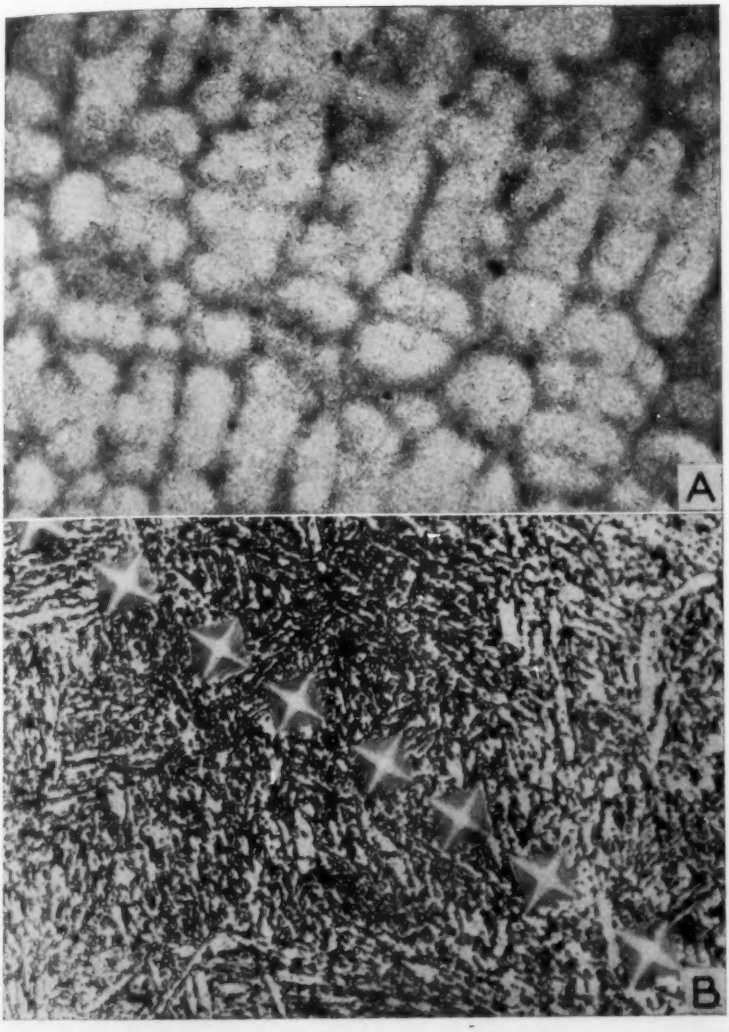


FIG. 20—SHOWING MICROSTRUCTURES OF TENSILE SPECIMENS FROM EDGE SECTION OF PLATE A IN THE QUENCHED AND DRAWN CONDITION AND AFTER ANNEALING. (A) (x50) AND (B) (x1000) ETCHED IN 2 PER CENT NITAL, WATER QUENCHED FROM 1650°F. AND DRAWN AT 1275°F. DIAMOND PYRAMID HARDNESS NOS. 249, 269, 310, 275, 269, 259, 240, 235. (C) (x50) AND (D) (x1000) IN 2 PER CENT NITAL. FURNACE COOLED FROM 1650°F. DIAMOND PYRAMID HARDNESS NOS. 362, 408, 474, 408, 254, 207, 194, 176.

78. Because of the depth of the columnar structure in blocks from heat No. 172, some Charpy specimens machined from the ends of the blocks were different from the majority of the specimens whose notches were surrounded by metal representative of the in-

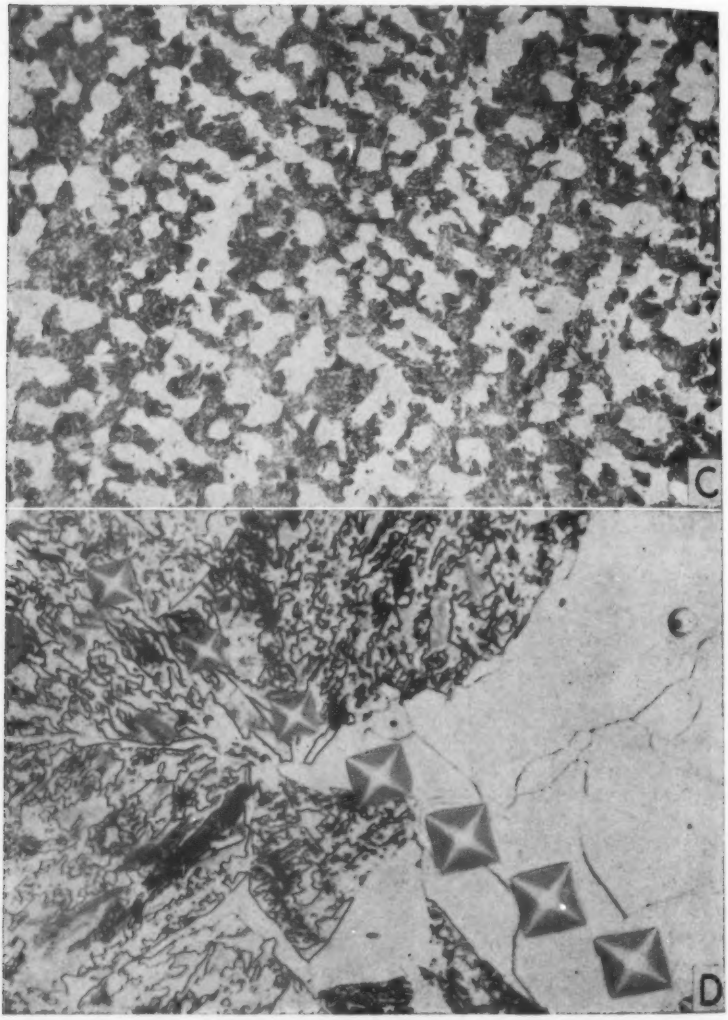


FIG. 20 (CONT'D)

Properties	*(A) and (B)*	*(C) and (D)*
BRINELL HARDNESS NO.	197	207
TENSILE STRENGTH, LB. PER SQ. IN.	101,300	111,600
ELONGATION IN 2-IN., PER CENT	25.8	15.5
REDUCTION OF AREA, PER CENT	52.6	18.8
IZOD, FT. LB.	71.2	5.2

teriors of the blocks. The end specimens representative of the columnar dendrites in the cast coupons were marked before ma-

chining and were tested separately at various temperatures to compare their results with the other specimens. The results of these separate breaks are recorded in Table 6.

79. Metallographic specimens were prepared from broken Charpy test specimens representative of the coupon from each heat which had received the prior normalizing treatment and which had absorbed close to the average energy value for its group when tested. Photomicrographs of representative structures are shown in Figs. 26 and 27.

Results of Tests

80. The Charpy-temperature curves indicate a susceptibility of

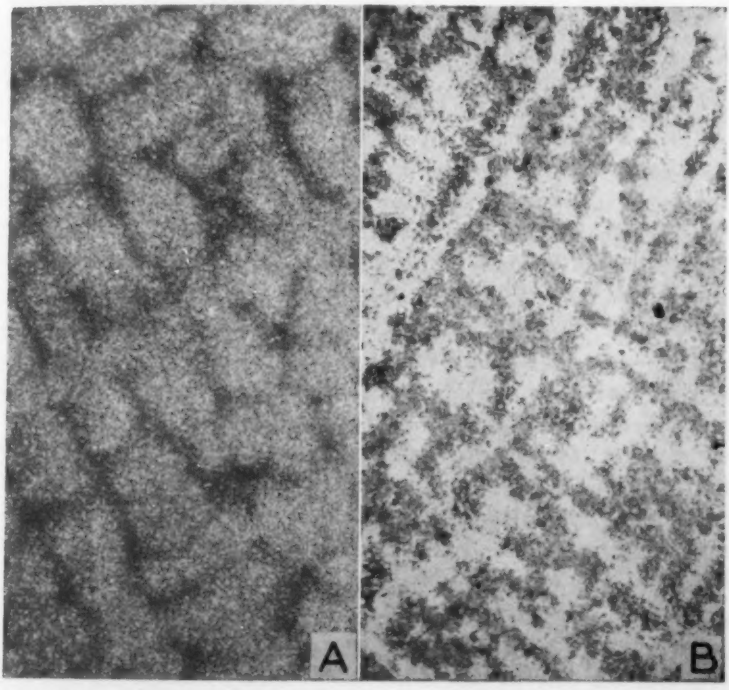


FIG. 21—SHOWING MICROSTRUCTURES OF TENSILE SPECIMENS FROM EDGE SECTION OF PLATE C IN THE QUENCHED AND DRAWN CONDITION AND AFTER ANNEALING. (A) WATER QUENCHED FROM 1600°F. AND DRAWN AT 1275°F. (B) FURNACE COOLED FROM 1600°F. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION x50.

Properties	*(A)*	*(B)*
BRINELL HARDNESS NO.	207	207
TENSILE STRENGTH, LB. PER SQ. IN.	104,000	112,800
ELONGATION IN 2-IN., PER CENT	25.2	15.0
REDUCTION OF AREA, PER CENT	58.6	18.8
IZOD, FT. LB.	62.9	9.2

the manganese-molybdenum composition to temper brittleness. In each steel the coupons quenched into water after drawing at 1200°F. exhibited greater ductility than companion coupons which were treated identically except that they were cooled in the furnace following the draw. The coupons from heat No. 164 which received the water quench after drawing exhibited the sharpest drop in Charpy values between –50°F. and –85°F., whereas the 2 coupons which were furnace cooled following the draw exhibited a substantial drop in Charpy value between 75°F. and 0°F. and a sharper drop between 0°F. and –50°F. The coupon from heat No. 164 which received the prior normalizing treatment and a water quench following the draw showed no rapid reduction in Charpy value until temperatures lower than –50°F. had been attained.

81. The coupons from heat No. 172 behaved similarly to the coupons from heat No. 164 in that the Charpy-temperature curves placed the 4 heat treating cycles in the same order with respect to their effects upon the ductility of the steel. The "normal" samples representative of the interior metal of the coupons for heat No. 172 exhibited a more rapid drop in Charpy value between 0°F. and –50°F. when the steel was heat treated according to schedule No. 1 than did heat No. 164, and the rate of drop of Charpy value between 75°F. and –85°F. was greater for the coupons which were furnace cooled from the draw in heat No. 172 than in heat No. 164.

82. Whereas the tensile test at room temperature fails to reveal any difference between castings quenched in water following the draw and those furnace cooled following the draw, and the Charpy test at room temperature indicates only a slight difference, the Charpy values at lower temperatures show considerable variations in behavior, indicating the value of the full Charpy-temperature curve in evaluating the differences in ductility.

83. Commercial treatments comprising an initial 3 to 8 hour soak at 1800 to 1850°F., often termed "homogenizing treatments," apparently add little to the ductility of a steel. Even the sensitivity of the Charpy-temperature test fails to reveal an improvement which justifies the added expense. For the 2 basic electric heats under consideration, this prior normalizing treatment resulted in a slight decrease in hardness and tensile strength, but more significant than these 2 properties was the relatively large drop in yield strength. Whereas the tensile strengths of both steels were lowered approximately 4,000 lb. per sq. in. (differences for average values), the yield value for No. 164 was reduced 6,000

lb. per sq. in. and the yield value for No. 172 was reduced 9,000 lb. per sq. in. by using the prior normalizing treatment. (The yield strength values were measured by the "drop of beam" method.)

84. That the 8 hour soak did not effect appreciable homogenization is shown in Fig. 27. In order to afford a more sensitive comparison, specimens ½-in. x ½-in. x 2-in., extending from one side of each coupon to the opposite side and midway between the bottom and the flame cut top surface (based upon the positions of the coupons as shown in Fig. 24), were heated to 1625°F., held one hour and cooled to 800°F. at 25°F. per hour. These samples were examined metallographically. Figure 28 illustrates the results obtained from this experiment. It is clearly recognized that any sojourn above the Ac_3 temperature for the steel will effect some degree of homogenization through diffusion of the alloying elements, but the evidence available indicated that, with the temperature and time employed for these experiments, little appreciable reduction in concentration gradients was effected.

85. The macrostructures of etched cross sections of the coupons, the microstructures of the Charpy specimens, the differences in the Charpy values, and the results of the annealing experiments indicated a considerable difference between the 2 heats of steel or in the conditions under which they were cast. Whereas the macrostructure of each coupon from heat No. 164 was uniform throughout, the coupons from heat No. 172 exhibited a rim structure of columnar dendrites extending from each of the cast surfaces to a depth of ½-in. to $\frac{9}{16}$-in. In this outer rim structure, there was less segregation and the steel seemed to possess higher hardenability as was evidenced by the microstructure of one of the "end" Charpy specimens. The values obtained for single fractures of these "end" Charpy specimens were superior to those of the interior structure of the same coupons and were superior to the average values for specimens of heat No. 164 treated identically. It is thought that some of the advantage in ductility of these "end" samples may have been gained through more complete hardening arising from an increase in hardenability and a faster rate of quench since they were close to the surface. More stress may be justifiably placed on the superior hardenability, since the "end" specimens from blocks No. 164 exhibited no such difference in properties. It is clearly recognized that too much importance must not be placed upon individual Charpy fractures,

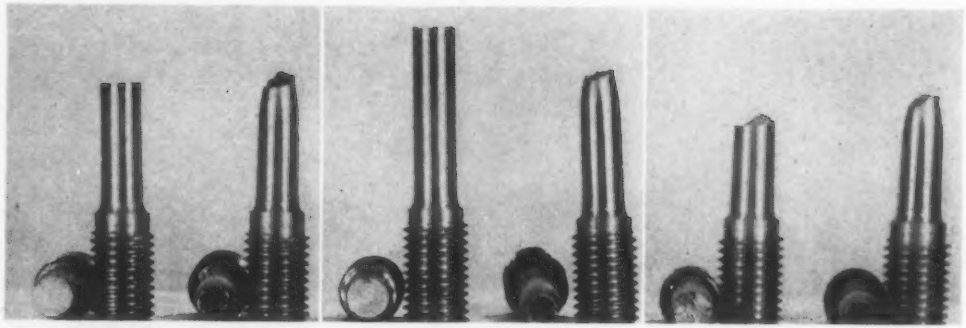


PLATE A PLATE B PLATE C

FIG. 22—FRACTURES OF TENSILE SPECIMENS FROM PLATES A, B AND C.

Properties	*Annealed*	*Water Quenched and Drawn*	*Annealed*	*Water Quenched and Drawn*	*Annealed*	*Water Quenched and Drawn*
BRINELL HARDNESS NO.	207	197	197	197	207	207
TENSILE STRENGTH, LB. PER SQ. IN. ..	111,100	101,200	106,800	100,900	113,200	104,000
ELONGATION IN 2-IN., PER CENT	12.8	25.0	12.5	26.5	14.8	25.2
REDUCTION OF AREA, PER CENT	14.1	55.2	12.3	56.2	20.2	58.6

but it is believed that the evidence presented here clearly indicates a trend worthy of consideration.

86. Examination of the microstructures of the broken Charpy specimens adjacent to the notches revealed that the structure of the coupons from heat No. 164 possessed greater hardenability

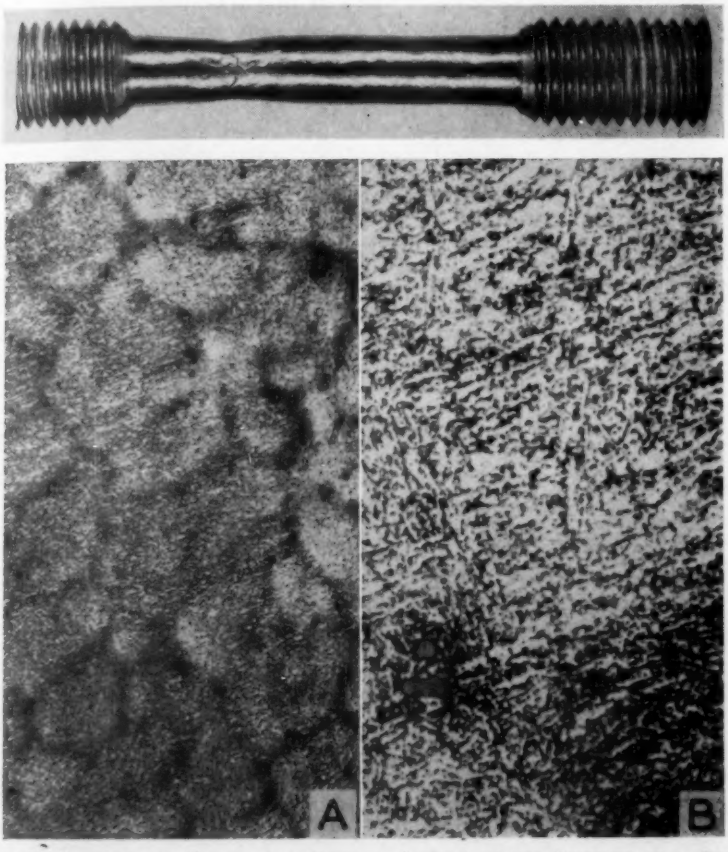


FIG. 23—SHOWING THE EFFECT OF A NETWORK PATTERN ON THE DUCTILITY OF A TENSILE SPECIMEN CONTAINING 0.32 PER CENT CARBON, 1.47 PER CENT MANGANESE, 0.72 PER CENT SILICON AND 0.53 PER CENT MOLYBDENUM, HEAT TREATED IN 2½-IN. SECTION, HELD AT 1650°F. FOR 2½ HOURS, WATER QUENCHED AND DRAWN AT 1250°F. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION (A) x50, (B) x1000.

Properties

BRINELL HARDNESS NO.	230
YIELD STRENGTH, LB. PER SQ. IN.	85,000
TENSILE STRENGTH, LB. PER SQ. IN.	109,400
ELONGATION IN 2-IN., PER CENT	19
REDUCTION OF AREA, PER CENT	39

than the "interior" metal of coupons from heat No. 172. Compare Figs. 26 and 27. The structure of Fig. 26B consists of drawn martensite. Figure 26A indicates that the structure is relatively uniform throughout. Figure 27B consists of drawn martensite accompanied by needles of ferrite in which no carbides have precipitated. The appearance of areas of this Widmanstätten distribution of the ferrite and carbide phases indicates that some decomposition of austenite took place in the temperature region between 1050 and 850°F. during the water quench. The Widmanstätten structure suffers little change during the subsequent drawing operation except for spheroidization and some agglomeration of the carbide phase. The more densely packed carbide spheroids resulted from drawing martensite which had formed at the *Ar″* upon quenching. Figure 27A reveals the distribution of the various micro-constituents. The darker etching network is composed of the drawn martensite structure.

87. Since the photomicrographs illustrate the structures at the vertical planes of symmetry parallel to the 8-in. x 2-in. faces of

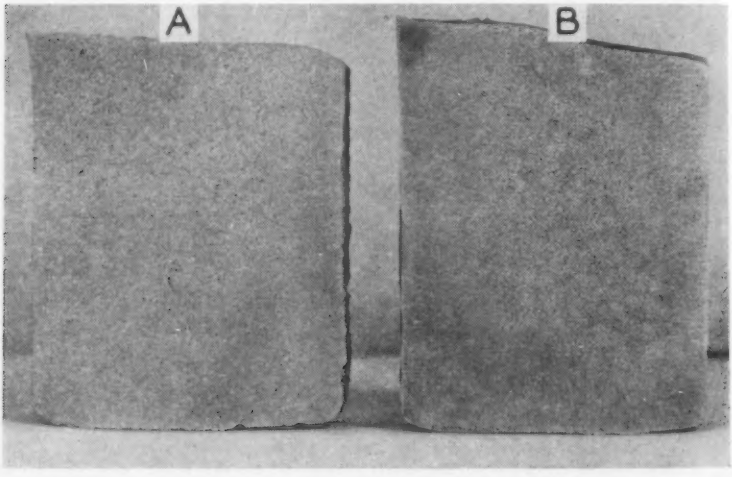


FIG. 24—MACRO-ETCHED CROSS SECTIONS REPRESENTATIVE OF COUPONS FROM (A) HEAT NO. 164 AND (B) HEAT NO. 172. NOTE RIM OF COLUMNAR DENDRITES IN COUPON FROM HEAT NO. 172.

the blocks, and since the blocks received identical treatments, the fact that the blocks from heat No. 172 contain appreciable quantities of high temperature products of austenite decomposition, while the blocks from heat No. 164 contain only a small quantity

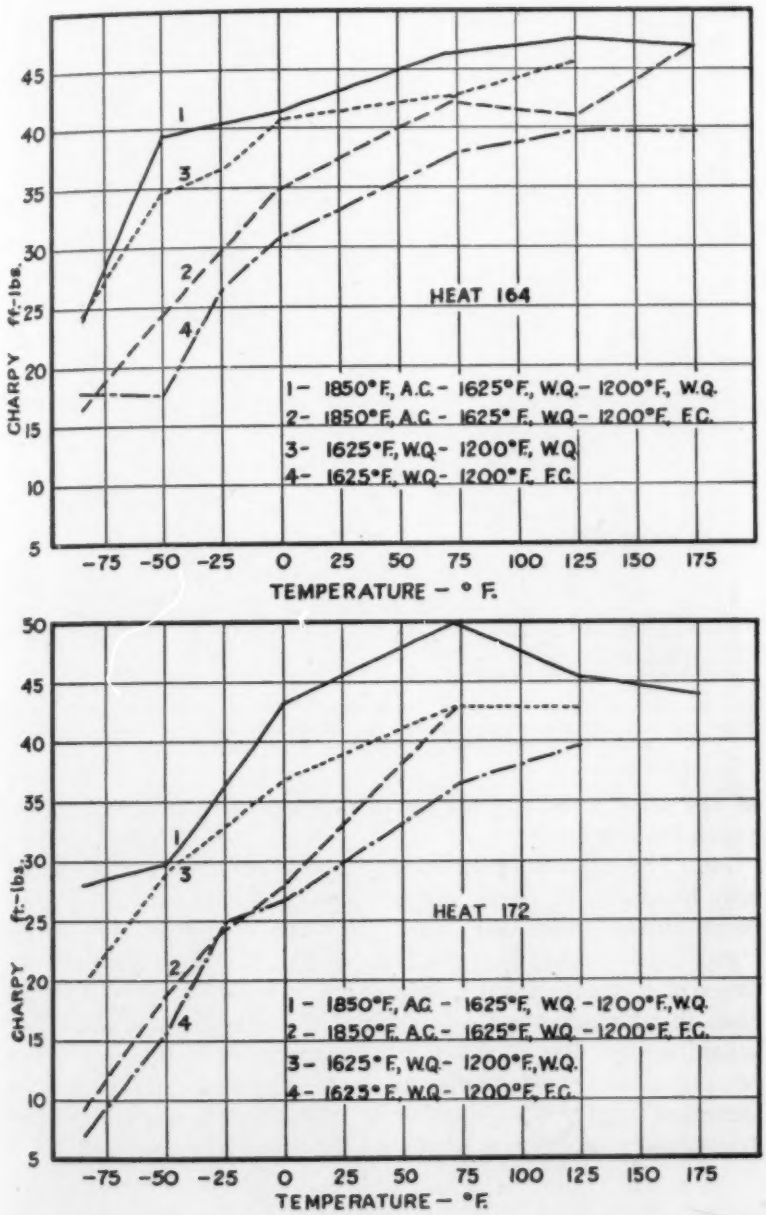


FIG. 25—CHARPY TEST DATA PLOTTED IN CHART FORM FOR COUPONS FROM HEATS NOS. 164 AND 172.

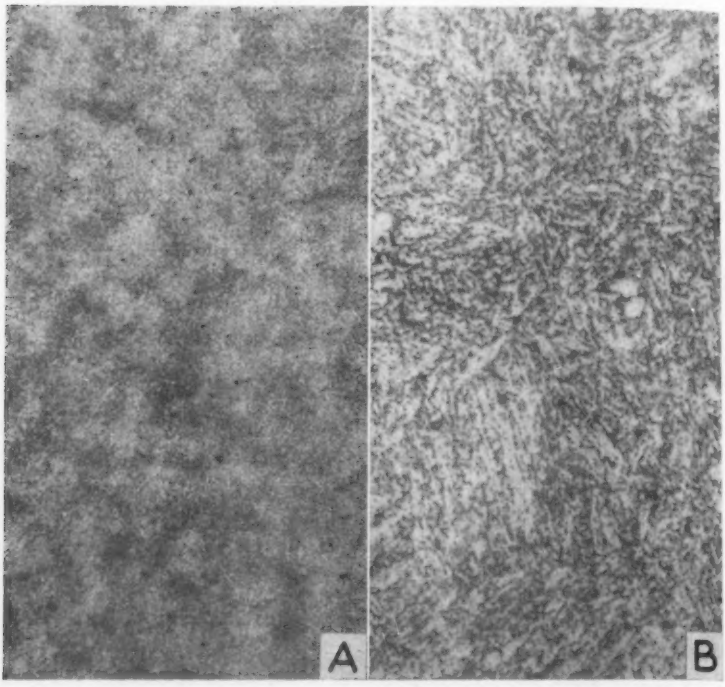


FIG. 26—MICROSTRUCTURE OF CHARPY TEST SPECIMEN REPRESENTATIVE OF COUPON FROM HEAT NO. 164. NORMALIZED, QUENCHED AND DRAWN. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION (A) x50, (B) x1000.

of the same products indicates a difference in hardenability between the 2 heats.

88. The superior properties of specimens from heat No. 164 may be attributed to the lack of network structures and to a uniform, drawn martensitic structure. The microstructure of the "end" specimens of heat No. 172 (see Fig. 27C) exhibits some evidence of segregation, but it is finer and more uniformly distributed than that apparent in the interior of the same coupon. At higher magnification (see Fig. 27D) the segregation is evidenced by a slight increase in the density of the spheroidized carbides, but the structure may still be considered drawn martensite. No higher temperature products of austenite decomposition are found.

CONCLUSION

89. Any factor which tends to raise the resistance to flow with respect to the resistance to cohesive failure will tend to reduce the

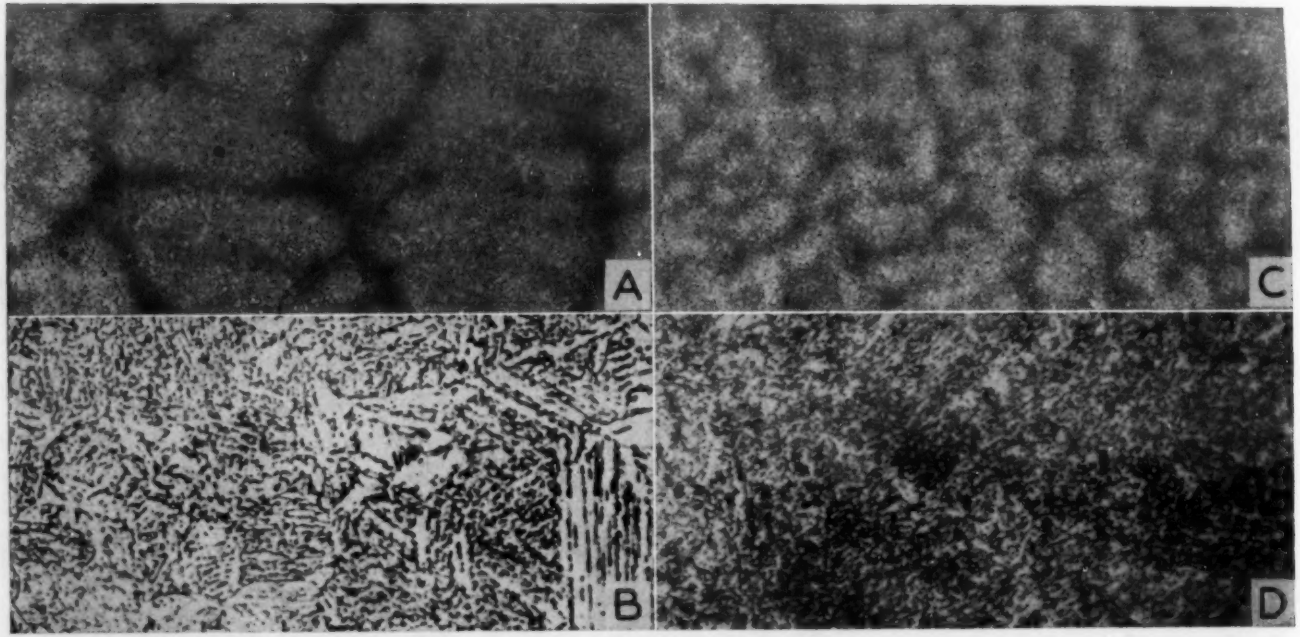


FIG. 27—MICROSTRUCTURES OF CHARPY SPECIMENS (A) (x50) AND (B) (x1000) REPRESENTATIVE OF "INTERIOR" STRUCTURE AND (C) (x50) AND (D) (x1000) REPRESENTATIVE OF "END" STRUCTURE OF COUPON FOR "END" SPECIMEN OF HEAT NO. 172. NORMALIZED, QUENCHED AND DRAWN. CHARPY AT −50°F. = 54.4 FT. LB. AS COMPARED TO AVERAGE OF 29.9 FT. LB. FOR "INTERIOR" SPECIMENS. ETCHED IN 2 PER CENT NITAL.

FIG. 28—PHOTOMICROGRAPHS OF SPECIMENS (A) ⅛-IN. FROM SURFACE AND (B) ONE-IN. FROM SURFACE OF COUPON FROM HEAT NO. 172. TOTAL TREATMENT: 1625°F., WATER QUENCHED, 1200°F., WATER QUENCHED, 1625°F., FURNACE COOLED. (C) ⅛-IN. FROM SURFACE AND (D) ONE-IN. FROM SURFACE OF COUPON FROM HEAT NO. 172. TOTAL TREATMENT: 1800°F., AIR COOLED, 1625°F., WATER QUENCHED, 1200°F., WATER QUENCHED, 1625°F., FURNACE COOLED. ETCHED IN 2 PER CENT NITAL. MAGNIFICATION ×50.

ductility of a steel casting. Various forms of discontinuity in the metal, such as porosity or the eutectic-type grain boundary inclusions, may lower the cohesive limit of the steel or may act as stress raisers, both of which will tend to bring the resistance to flow nearer to the resistance to fracture, and the ductility is thus diminished. Where high ductility is desired in a steel casting, it is imperative that the metal be cast sound and free from grain boundary sulphide inclusions.

90. The solidification pattern and the degree of segregation of alloying elements which are dependent upon the rate of solidification have been found to exert an important influence upon the ductility of a steel casting at a given hardness, chiefly through their effects upon hardenability and the distribution of micro-constituents. When a steel is highly segregated, its hardenability is lower than for the average composition and a faster rate of quench will be required to produce full hardening. If the critical quenching rate is not exceeded upon cooling from the austenitic state, regions rich in alloy content will generally transform at temperatures lower than those at which transformation will take place in the regions less rich in alloying elements. The resulting structure will, therefore, consist of 2 or more micro-constituents varying in their mechanical properties and distributed in a pattern which resulted from the "coring" which took place during solidification. If the harder structure is distributed in a network pattern, or in any manner which definitely breaks up the continuity of the softer, more ductile matrix, plastic deformation in the latter will be restricted and the resistance to flow will be appreciably increased with respect to the resistance to fracture. The steel in this condition will be susceptible to failure in a brittle manner with a low absorption of energy and will, therefore, be less fit for service applications in which high concentrations of 3-dimensional stress may prevail or where the rate of load application is moderately high.

91. In order to obtain the maximum ductility at any given hardness, the steel must be quenched from the austenitic state at such a rate that it will be fully martensitic by the time it has reached room temperature. It should then be drawn to the desired hardness. Such a procedure should ensure a uniform microstructure of drawn martensite throughout. When the steel is quenched at a rate just slightly less than the critical cooling rate for the regions lowest in concentration of alloying elements, the austenite

in these regions will transform at temperatures in the vicinity of the nose of the S-curve forming the Widmanstätten structure in medium carbon steels. After drawing, these regions will be softer, weaker and possibly more ductile than the drawn martensite. Their lower hardness and inability to deform plastically, due to the restraint imposed by the harder surrounding matrix, result in a condition in which the cohesive limit is lowered with respect to the resistance to flow, and the steel will be more susceptible to a brittle fracture.

92. When a cast alloy steel which is highly segregated is normalized or annealed, there is always the possibility that there will result a soft, ductile matrix which will contain within it a harder network that will restrict the plastic deformation of the matrix, thereby raising the flow stress with respect to the resistance to fracture and thus decreasing the ductility of the steel.

93. The columnar dendritic structure often found at the surfaces of steel castings, when sound, has been found to possess higher hardenability than the interior, "equiaxed," or "granular" structure of the same casting. The distribution of the alloying elements is more uniform and the solidification pattern is finer. Such a structure, when properly heat treated, will possess excellent ductility as indicated by low temperature Charpy tests.

94. The present method for evaluating the ability of a given heat of steel to perform satisfactorily in a certain application consists in casting a coupon of the steel, heat treating this coupon according to the schedule set up for the larger casting, and running tension and notched-bar tests on samples machined from it. The coupons are usually small, 1-in. to 1½-in. thick in order to facilitate the machining of specimens, yet they are often supposed to represent the metal in a casting whose sections may be 4- to 5-in. thick. Such coupons cannot be considered adequate samples of the material in the heavy sections of a large casting. Even though it be assumed that the conditions were correct for the metal in the heavy section to solidify to a sound mass throughout and that no grain boundary inclusions could be found, there are still significant differences in the 2 cast sections. The coupons freeze rapidly, resulting in a finer crystal structure with less segregation of alloying elements than will obtain in heavier sections. The hardenability of the steel in the small coupon may be considerably greater than that of the same steel after it solidifies at the interior of a

larger casting. This difference in hardenability and the difference in the distribution of the alloying elements, due to "coring," may result in far superior properties in the smaller casting than those which it is possible to develop in the larger casting with the same heat treatment.

95. There are indications that the rate of solidification may be as important a factor in controlling the characteristics of cast steel as it is in controlling the characteristics of cast iron and due consideration should be given to the testing of specimens which actually represent the metal in the part to be cast when evaluating a steel for the job. In order to accomplish this, a coupon should be cast which will solidify under conditions obtained at the interior of the casting it is to represent. When heat treated, the rates of cooling from the austenitic state should be similar in coupon and casting.

96. The fact that in normalized castings of some alloy steels, a matrix of Widmanstätten structure with a network of martensite may be formed as the result of "coring" and that this structure possesses low ductility indicates that considerable improvement in the mechanical properties of large castings may be realized by employing the principles of isothermal transformation. After austenitizing, the casting may be air cooled to the (temperature of) nose of the S-curve for the composition, then loaded into a furnace whose temperature is at the same level. The casting may be held in the furnace at that temperature until all the austenite has transformed. After this transformation has been completed, the casting may be cooled to atmospheric temperature in air. Since the transformation in all parts of the casting is forced to take place at one temperature, the microstructure of the steel should be uniform throughout and ductility should be high. For such a treatment a steel need have only sufficient alloy to prevent austenite decomposition at temperatures above the nose of the S-curve when cooled at the rate prevailing in the given section size and a uniform distribution of carbon in the austenitic state.

ACKNOWLEDGMENT

97. The author gratefully acknowledges the valuable assistance given him in the preparation of this paper by the members of the staff at the Research Laboratory of the Climax Molybdenum Company.

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Refractories in the Non-Ferrous Foundry Under War Conditions

By M. H. Berns*, Buffalo, N. Y.

Abstract

Modern metal demand requires that the best refractory available be used in every non-ferrous melting furnace. The relationship of furnace requirements to the properties of common refractories is discussed with the aid of a chart showing such properties.

Introduction

1. The development of equipment and processes for melting metal has been inextricably bound to the refractories available. In many cases, the utilization of processes has been retarded due to the lack of satisfactory refractories. In other cases, refractories have been developed and are in use in one process and have not been successfully applied to others. Since no perfect refractory has yet come into being, this see-saw process of refractory development has continued.

2. The writer, in this paper, would like to point out ways in which the adoption of more suitable refractories can be accomplished. First, if available refractories are not suitable for a certain process, the foundryman can speed up the development of a suitable refractory if he can tell the refractories manufacturer just what he needs, and second, by being familiar with his needs he can more readily adapt specialized refractories to his operations.

3. At the present time, responsibility for success in our war effort lies directly on our metallurgical industries, of which our non-ferrous foundries are no small part. In order to produce much needed metal castings of better quality and in greater quantity than ever before, the foundryman must have at his disposal the very best that the refractories industry can offer. He must be able to determine in advance what refractories are most likely to give him the service he requires. He must insist upon getting even better refractories as he needs them and he must use the best available refractory at all times.

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* Electro Refractories and Alloys Corp.

Note: This paper was presented before a Foundry Refractory Session of the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1942.

OPERATING CONDITIONS

4. Under war conditions many factors, in the selection of a refractory, are changed. Furnaces are "pushed" to their limits, resulting, usually, in higher operating temperatures and more severe operating conditions generally.

5. Any refractory change which will increase the life of a furnace by a few weeks or days or hours means that much more metal produced; means that much more labor saved, which, in these days of scarce labor, is a large factor; means an overall saving on weight of refractory used, which also helps to ease a critical situation. With these things in mind we believe it is the duty of every foundryman operating a furnace of any kind to inspect critically the refractories he is using. Perhaps the refractories he is now using have given economical service for years, perhaps his furnaces are the same, perhaps his fuels, metal, slags, and methods are the same; he may still be imposing much different conditions on his refractories simply because he is now running two or three shifts instead of one, or is taking four heats from a furnace instead of three.

Refractory Selection

6. How, then, may the foundryman set about to improve his refractory practice? We should like to try to answer this question. In considering the selection of the proper refractory for an application, three things must be keep in mind: First, the service conditions which will be imposed on that refractory; second, the properties which qualify the refractory to withstand those conditions, and third, whether the selected refractory is economical as compared to others.

7. As to the first factor, no one is in a better position to evaluate and control service conditions than the foundryman himself. For the second, properties of available refractories are flexible; they may be changed to give preferential maxima to one property at the expense of one or more others; and for the third, only actual service can determine whether any one refractory is more economical than another. It is true that fairly accurate estimates can be made, but conditions of use vary so greatly that only actual trial will answer this question. For this reason we shall not discuss the third factor.

SERVICE CONDITIONS WHICH AFFECT REFRACTORIES

8. With such a wide variety of fuels, furnaces and metals in

use in the non-ferrous foundry, it may seem impossible to give any rules for defining the service conditions to which the refractory will be subjected. This is not the case. Many service requirements are common to all, or nearly all applications, others are applicable only to special cases. Among the most important conditions imposed on a refractory are: Working temperature, temperature variation, metal, slag, furnace atmosphere, and movement of the metal and furnace gases with respect to the refractory.

Temperature

9. In the case of the first: temperature, we must remember that temperature requirements vary greatly, not only from one furnace to another but in different parts of the same furnace, and even in different sections of the same part. For example, temperatures in a crucible furnace melting copper vary from temperatures in a low-frequency induction electric furnace melting copper. Temperatures in the crucible furnace are different in the crucible than they are on the lining; and temperatures on the crucibles are different above and below the metal line. We must also bear in mind that, in the case of the crucible, the temperature is obtained throughout the crucible, since the heat must pass through the walls of the crucible to the metal, whereas, in the case of the lining, only the inner surface reaches the working temperature. However, here again the temperature on the lining is greater than it is inside the crucible since a temperature differential must exist to force the heat through the refractory to the metal. All of these things must be considered in the selection of a refractory to resist the temperature developed.

10. The condition of temperature variation has a marked effect on the selection of the refractory. If the refractory is subjected repeatedly to rapid changes in temperature, it is obvious that a different refractory will be required than when a uniform temperature exists during the entire life of the refractory. Returning to our previous example, the crucible in the crucible furnace must be able to withstand severe changes in temperature, whereas the temperature of the refractory in the low-frequency induction furnace remains fairly constant.

Variable Furnace Conditions

11. Other variable service conditions imposed on the refractory are the metal being melted, the slag on the metal, and the furnace atmosphere. It is apparent that neither the metal nor the slag can

have any marked reaction with the refractory or one, or both, of two things may happen; the refractory will have a very short life and the metal is liable to be contaminated; both of which are to be avoided. Also, the refractory must be able to withstand the load of molten metal, which will vary with the type of metal. The refractory must also not react or be affected by the furnace atmosphere.

12. The movement of the metal, the slag, and the furnace gases, if any, with regard to the refractory, is very important. This movement is present in practically all furnaces, and may be fast, slow, steady or erratic. Metal movement will cause erosion of the refractories and possible dislodging of particles of the refractory, which will cause contamination of the metal. Slag movement will cause erosion of the refractory, and this movement may also dislodge particles of refractory, which find their way into the metal and cause contamination. The above service conditions are those common to all non-ferrous melting furnaces, and must be taken into account in the selection of the refractory.

13. In certain furnaces it is essential that the refractory transmit heat rapidly. For example, a crucible must be able to pass the heat from the outside of the crucible to the metal.

14. In other furnaces, resistance to the passage of electric current is essential. For example, in electric arc furnaces the refractory surrounding the electrodes must be a nonconductor of electricity or the circuit will be shorted.

15. These, then, are the service requirements which we have, and which must be met by the refractory if satisfactory service is to be obtained.

PROPERTIES OF REFRACTORIES

16. Having considered the conditions under which the refractory must operate, let us examine the properties of refractories which will enable us to make a selection for any particular set of conditions.

17. The writer has prepared a chart (Table I) showing many properties of common refractories in use in the non-ferrous foundry. The properties shown are typical for each type of refractory, but, as previously mentioned, are subject to considerable variation, depending upon the method of manufacture, firing temperature, bond used, and many other variables.

Table 1

PROPERTIES OF REFRACTORIES

	Fused Magnesia	*Type M Silicon Carbide*	*Type H Silicon Carbide*	*Carbon-Bond Silicon Carbide*	*Clay Graphite*	*Carbon*	*Silica*	*Low Heat Duty Fireclay*	*High Heat Duty Fireclay*	*Super Heat D Firecl*
Softening Point (P.C.E.†)	Cone 40 1885°C.	Cone 36 1810°C.	Cone 39 1865°C.	Does Not Soften	Cone 31 1680°C.	Does Not Soften	Cone 32 1700°C.	Cone 19 1520°C.	Cone 31 1680°C.	Cone 3 1745°C
Load Bearing at High Temp.	Fails 1550°C.	Fails 1500°C.	No Deformation 1650°C.	No Deformation 1650°C.	Fails 1500°C.	No Deformation 1650°C.	Fails 1700°C.	.....	1.5 per cent Deformation 1350°C.	1 per c Deform 1600°C
Spalling Resistance	Poor	Excellent	Excellent	Excellent	Very Good	Excellent	Very Poor	Poor	Fair	Good
Metal Resistance	Good	Good	Good	Good except Cr, Ni	Good except Cr, Ni	Excellent except Cr, Ni	Good	Good	Good	Good
Resistance to Basic Slag	Good	Poor	Poor	Poor	Fair	Very Good	Very Poor	Poor	Poor	Fair
Resistance to Acid Slag	Very Poor	Very Good	Very Good	Very Good	Very Good	Very Good	Good	Good	Good	Good
Resistance to Oxidation	No Reaction	Poor Unless Protected	Poor Unless Protected	Poor Unless Protected	Fair	Very Poor Unless Protected	No Reaction	No Reaction	No Reaction	No React
Resistance to Reduction	Good	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	Fair	Fair	Fair
Strength at High Temp.	Good	Good	Very Good	Good	Good	Good	Good	Poor	Fair	Good
Porosity, per cent	25	23	18	30	25	25	30	15	20	20
Resistance to Abrasion	Poor	Excellent	Excellent	Poor	Good	Poor	Fair	Good	Good	Good
Thermal Conductivity @ 2192°F., B.t.u./hr./ft.²/°F./in.	29	90	95	100	55	18	12	11	11	10
Electrical Resistivity @ 1200°C., ohms/cm³	94,700	.....	29,500	0.008	Low	0.008	15,700	50,000	50,000	50,0
Weight 100 cu. in. (9-in. Str.), lb.	9½	8	9	6½	6	5½	5½	7½	7½	7½
Coefficient of Expansion x 10^{-5}, in./in./°C.	1.6	0.5	0.5	0.3	0.7	0.8	1.2	0.6	0.6	0.6
Chemical Composition	MgO	SiC 70-80 per cent	SiC 85 per cent	C+ SiC	$Al_2O_3.SiO_2$ + C	C	SiO_2	$Al_2O_3.SiO_2$ 30 per cent Al_2O_3	$Al_2O_3.SiO_2$ 40 per cent Al_2O_3	Al 50 Al

* 1000°C.
† Pyrometric Cone Equivalent.

Table 1

PROPERTIES OF REFRACTORIES

arbon-Bond Silicon Carbide	*Clay Graphite*	*Carbon*	*Silica*	*L Heat Fire*
Does Not Soften	Cone 31 1680°C.	Does Not Soften	Cone 32 1700°C.	Cone 1520°
No Deformation 1650°C.	Fails 1500°C.	No Deformation 1650°C.	Fails 1700°C.	.....
Excellent	Very Good	Excellent	Very Poor	Poor
Good except Cr, Ni	Good except Cr, Ni	Excellent except Cr, Ni	Good	Good
Poor	Fair	Very Good	Very Poor	Poor
Very Good	Very Good	Very Good	Good	Good
Poor Unless Protected	Fair	Very Poor Unless Protected	No Reaction	No Reac
No Reaction	No Reaction	No Reaction	No Reaction	Fair
Good	Good	Good	Good	Poor
30	25	25	30	15
Poor	Good	Poor	Fair	Good
100	55	18	12	11
0.008	Low	0.008	15,700	50,00
6½	6	5½	5½	7½
0.3	0.7	0.8	1.2	0.6
C+ SiC	$Al_2O_3.SiO_2$ + C	C	SiO_2	Al_2O_3 30 pe Al_2O_3

Low Heat Duty Fireclay	*High Heat Duty Fireclay*	*Super Heat Duty Fireclay*	*Mullite*	*Fused Alumina*
Cone 19 1520°C.	Cone 31 1680°C.	Cone 33 1745°C.	Cone 36 1810°C.	Cone 42 2015°C.
.....	1.5 per cent Deformation 1350°C.	1 per cent Deformation 1600°C.	Fails 1600°C.	No Deformation 1650°C.
Poor	Fair	Good	Good	Good
Good	Good	Good	Good	Good
Poor	Poor	Fair	Good	Good
Good	Good	Good	Fair	Poor
No Reaction	No Reaction	No Reaction	No Reaction	No Reaction
Fair	Fair	Fair	Fair	Fair
Poor	Fair	Good	Good	Very Good
15	20	20	24	20
Good	Good	Good	Good	Good
11	11	10	11	24
50,000	50,000	50,000	11,500	*2,400,000
7½	7½	7½	8	10
0.6	0.6	0.6	0.5	0.7
$Al_2O_3.SiO_2$ 30 per cent Al_2O_3	$Al_2O_3.SiO_2$ 40 per cent Al_2O_3	$Al_2O_3.SiO_2$ 50 per cent Al_2O_3	$3Al_2O_3.2SiO_2$	Al_2O_3

UNIV. OF MICH.

Temperature

18. As previously stated, a refractory must be able to withstand the temperature encountered in the furnace. The terms which define this property are the softening point and load bearing capacity at high temperatures. The softening point of a refractory is of little consequence for practical purposes, since refractories are not suitable for operation at their softening point; also, refractories vary greatly in the relation of the softening point to the safe working temperature. Silica brick, for example, may be employed safely at temperatures very close to its softening point, whereas fireclay brick may not be employed within several hundred degrees of the softening point. The other factor is the ability to withstand load at high temperatures. Values obtained on a refractory under load at high temperatures can be used to estimate whether a refractory will stand up at a given temperature.

Chemical Action

19. The ability of a refractory to withstand chemical action of the metal, slag, fluxes, and furnace gases can be determined by the composition of the refractory as compared to the composition of the slag, the metal, and the atmosphere present. Basic refractories, such as magnesia, should not be used in contact with acid slags, with which they react. Also, there must be no reaction between the refractory and the furnace atmosphere.

Movement

20. The ability of a refractory to withstand the erosive action of moving slag and metal is reflected in its strength and density, and is usually expressed as its resistance to abrasion.

Heat Flow

21. The ability of a refractory to transfer heat is known as its thermal conductivity. Test values obtained will be found to give comparable results in service, even though the actual heat flow is not the same as the test results would indicate.

Electrical Resistance

22. The electrical resistivity of a refractory measures its ability to prevent the passage of electricity. Here again, test results indicate quite clearly what may be expected from the refractory in service.

Other Refractory Properties

23. Many other properties of refractories are important, not so much in the selection of the refractory but in predicting and providing for what will happen in use. For example, the weight per unit volume of the refractory will influence the strength of the furnace supports. The coefficient of expansion must be known in order that suitable provision may be made to care for such expansion.

24. Consideration of properties shown in Table 1 may be used as a guide in the selection of a refractory. The increased use of refractories made from electric furnace products indicates what may be done by the adoption of refractories to meet specific service requirements. Refractories of this type, which include silicon carbide, fused alumina and fused magnesia, cost many times as much as other refractories, yet their use is increasing because they have properties which are of particular benefit in certain types of service, and longer life justifies their use even though the initial cost is greater.

25. Silicon carbide refractories are indicated whenever severe spalling conditions are encountered: whenever severe abrasion is present and whenever high heat conductivity is required. Fused alumina refractories are indicated whenever severe temperature conditions are encountered in conjunction with severe oxidizing conditions or whenever resistance to basic slags is required. Fused magnesia refractories are indicated for the same conditions as fused alumina, the magnesia having better resistance to very basic slags.

CONCLUSION

26. It should be kept in mind that many of the values for specific properties may be varied through quite wide limits. For example, a pre-burned refractory will have somewhat different properties than one installed as a ramming material and fired in service, even though the material may be the same. However, the foundryman, by considering the properties shown in Table 1, may determine what type of refractory is most likely to meet his conditions. Also, by determining what properties of refractories need improvement, he may be able to advise the refractories manufacturer as to his requirements.

Heavy Gray Iron Castings Produced by Modern Controlled Methods

By Samuel Appelby*, Buffalo, N. Y.

Abstract

This paper describes the application of modern, controlled methods to the production of large, heavy, gray iron castings. The author mentions some of the important changes and methods that have been developed in recent years, which are replacing haphazard, rule-of-thumb operations. Most of these developments have been accepted and successfully applied by many foundries producing light and medium weight castings made in green sand, dry sand or skin-dried molds. These same methods can be and are being profitably applied to produce heavy castings weighing up to 125 tons, made in dry sand and loam. Standardization and effective control of materials, engineering and planning to determine method of procedure and proper coordination of all operations are essential factors to produce heavy castings successfully. Illustrations show typical heavy castings produced by these methods.

1. The gray iron foundry industry has made greater advancements in the last few years than in any similar period in its history. Many radical changes have been made in engineering, design, specifications, physical properties and production methods. The result is a greatly improved product that is finding new and broader uses, as well as reclaiming markets that have been lost to competition.

2. New production methods have been developed to insure the uniform, high quality demanded by prudent casting buyers. Progressive foundries use scientifically controlled methods, developed in the laboratory and proven in the foundry, to profitably replace former, wasteful rule-of-thumb operations.

* Foundry Superintendent, Buffalo Foundry & Machine Co.

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FIG. 1—TURBINE RUNNER CASTING ASSEMBLED IN CORES. FIFTEEN FT. DIAMETER, 9 FT. HIGH. WEIGHT 62 TONS. METAL POURED 70 TONS. POURING TEMPERATURES 2580°, 2610°, 2630°F. POURING TIME 4 MIN. 50 SEC.

3. Highlighting the developments that have already proven their worth in the production of high quality castings and more profitable operations are sand reclamation, sand control, synthetic sands, salvage of materials, modernized mechanical equipment, improved methods for drying molds and cores, better use of gates and risers, directional solidification, scientific cupola practice, the importance of pouring temperatures and speeds, and the use of alloys.

4. Many of these developments are already being profitably used by most of the successful foundries producing light and medium weight castings. The same advantages can be enjoyed

when these methods are applied to the production of large, heavy castings.

5. This paper describes how the Buffalo Foundry and Machine Co. uses these modern controlled methods to produce high quality, medium and heavy gray iron castings, ranging in weight from a few hundred lb. up to 125 tons.

6. These castings are made in flasks and in pits. The molds and cores are made in dry sand or loam, using full patterns, split patterns, skeletons and sweeps. They meet the rigid specifications of the chemical industry, the builders of large machine tools and internal combustion engines.

7. Following a definite program of development and modernization to meet the more exacting demands of the industry, this company has made many changes in its foundry practice and methods.

8. Standardization and effective control are applied to all foundry operations, including sand, blacking, drying, gates, risers, venting, cupola operation, pouring, shake-out and cleaning. All of these operations must be properly coordinated and controlled to produce heavy castings successfully and warrant careful consideration.

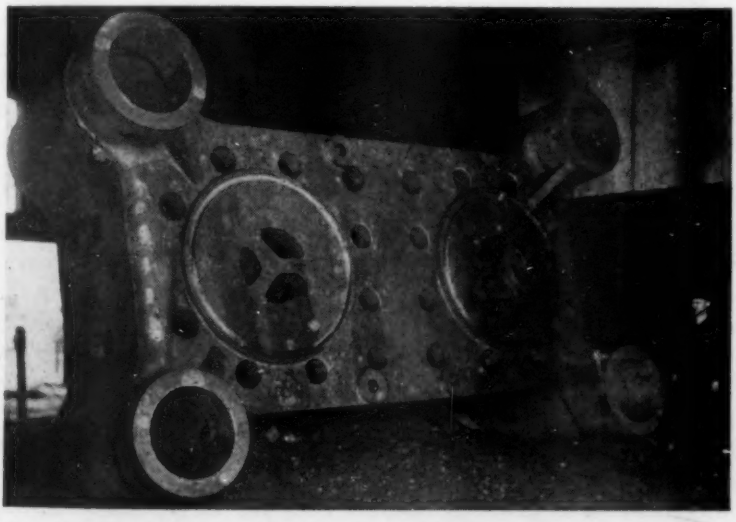

FIG. 2—SLIDE FOR 5000 TON HYDRAULIC PRESS MADE IN LOAM. WIDTH 10 FT. 3-IN., LENGTH 16 FT., 7-IN., HEIGHT 5 FT., 10-IN. WEIGHT 65 TONS. METAL POURED 72 TONS. POURING TEMPERATURES 2550°, 2560°, 2580°F. POURING TIME 6½ MIN.

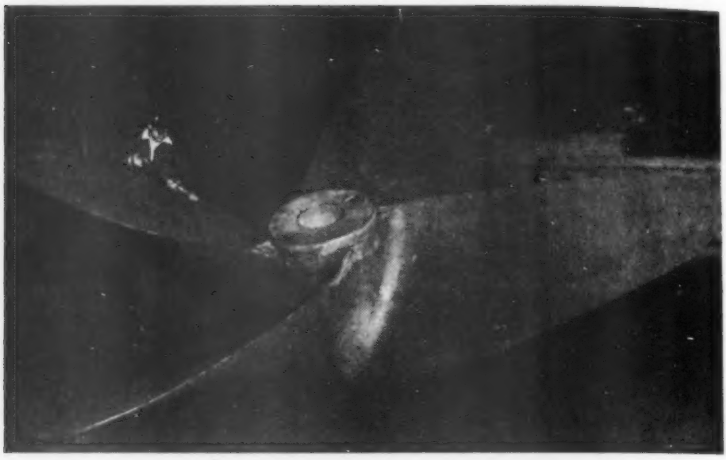

FIG. 3—FOUR BLADE PROPELLER MADE IN DRY SAND. DIAMETER 18 FT. 10-IN. WEIGHT 14 TONS. METAL POURED 16 TONS. POURING TEMPERATURE 2550°F. POURING TIME ONE MIN., 40 SEC.

SAND

9. One of the foremost advancements in the foundry industry is the use of synthetic sand. Today, its use is accepted as standard practice in most of the steel foundries and large production gray iron foundries in this country.

10. Its application in gray iron foundries has been largely confined to the production of light and medium weight castings made in green sand, dry sand or skin-dried molds. The advantages of synthetic sand, when properly controlled, have been definitely proven. Many papers have been written on the subject and considerable research work still continues.

11. In order to produce the wide variety of castings demanded from a jobbing shop, this foundry handled annually several thousand tons of molding sand. To the cost of these materials was added the expense of unloading, of storage and of eventual haulage to the dump of the discarded sands. The problem was further complicated by the numerous mixtures of facings and core sands considered necessary to produce the various classes of work.

12. Our prime objective was to develop and prepare economically a highly refractory sand, with the proper durability to withstand high pouring temperatures for large, heavy castings and to maintain proper controls over permeability, dry compression strength and the rate of collapsibility.

13. To accomplish this purpose, one of the important changes made in this foundry was the installation of a system to prepare synthetic sand from reclaimed molding and core sands, which were formerly discarded. This system consists of—

(1) Sand storage pit for all shake-out sand from molds and cores.

(2) Complete sand reclamation and salvage unit, with fines removal under control.

(3) Sand preparation unit, with storage facilities for processed sand.

(4) Sand testing laboratory.

14. The outstanding improvement resulting from this system has been the development of *one* facing sand mixture and *one* heap sand mixture. These two sands have been standardized and are applied to all classes of work made in dry sand or loam. *They are used for molds and cores alike.*

15. The use of this sand allows us to pour the iron at high temperatures, producing the same relative improvement of physical properties in heavy castings as that obtained in light and medium weight castings poured at similar temperatures.

BLACKING

16. One grade of high quality blacking has now been stand-

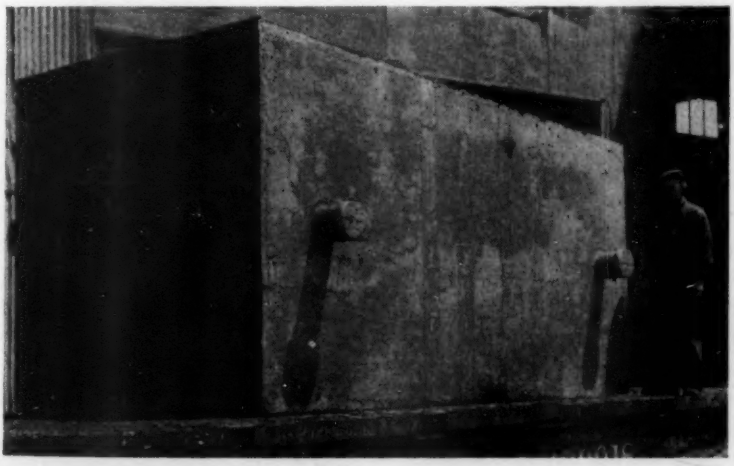

FIG. 4—ANVIL BLOCK MADE IN LOAM. LENGTH 13 FT., WIDTH 6 FT., HEIGHT 6 FT. WEIGHT 105 TONS. METAL POURED 125 TONS. POURING TEMPERATURES 2510°, 2520°, 2530°, 2540°, 2560°F. POURING TEMPERATURE FOR RISER 2700°F. POURING TIME 8 MIN.

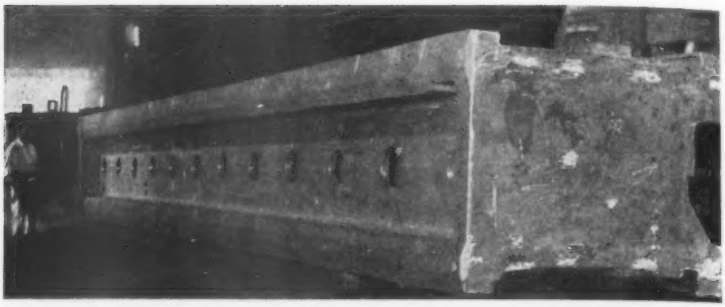

FIG. 5—PLANER CROSS RAIL MADE IN DRY SAND. LENGTH 34 FT., WIDTH 4 FT., DEPTH 5 FT., 2-IN. WEIGHT 50 TONS. METAL POURED 58 TONS. POURING TEMPERATURES 2560°, 2580°, 2620°F. POURING TIME 4 MIN.

ardized. This blacking is blended with a binder by the manufacturer and is easily prepared by adding sufficient water to give a hydrometer reading of 40° Beaumé. Mixing takes place in a cast iron tank, having a capacity of 150 gal. and provided with a motor driven agitator. This blacking is applied to all molds and cores with spray guns and then brushed to a smooth finish.

DRYING

17. Since the permeability of the sand permits free and easy venting, it has been possible to shorten the drying time and lower the temperatures.

18. Taking advantage of this feature, the method of drying pit molds has been changed by adapting portable hot air mold dryers to replace salamanders and perforated gas pipes with their cumbersome connections.

19. These portable mold dryers, designed and built in our own shops, use a mixture of air and gas as fuel and deliver the products of combustion, under pressure, at any desired temperature, thereby eliminating heat waste. The heat is conducted into one end of the pit which has been covered with its copes. The moisture is exhausted through properly located vents at the opposite end of the pit. A uniform temperature of 450°F. (232°C.) is automatically maintained with the use of a recording thermometer set up adjacent to the job, with the bulb properly located inside the pit. The temperature chart acts as a guide for regulating the control valves on the mold dryer.

20. The pit and its copes are quickly and economically dried in one operation, with a heat penetration of from 2- to 6-in., as

desired. Depending on the size of the pit, the drying time required to obtain this penetration runs from 12 to 24 hours.

21. Large flasks are dried in a similar manner, by using suitable pipe and elbow connections with the dryer. This method eliminates moving flasks to and from the ovens and avoids the possibility of cracked molds, caused by handling.

GATES AND RISERS

22. Changes have been made in the methods of gating, risering and feeding of heavy castings. Ingates and downgates are made in dry sand cores, with a range of standard sizes established for each. Proper size of gates is predetermined for each casting, selected to insure rapid pouring and so placed that hot metal may enter without directly striking cores or mold surfaces.

23. The number and location of gates is arranged so the entire mold may be filled with metal of approximately uniform temperature. All parts of the casting are thus permitted to cool at a more uniform rate, minimizing internal strains and distortion.

24. This practice has made possible the elimination of many risers, and the use of feeding rods has been abandoned. The size

FIG. 6—CAUSTIC POT MADE IN LOAM. DIAMETER 10 FT., DEPTH 7 FT. WEIGHT 15 TONS. POURING TEMPERATURE 2550°F. POURING TIME ONE MIN., 15 SEC.

FIG. 7—ENGINE FRAME MADE IN DRY SAND. LENGTH 20 FT., WIDTH 7 FT., 6-IN., DEPTH 8 FT., 4-IN. WEIGHT 24 TONS. METAL POURED 30 TONS. POURING TEMPERATURES 2570°, 2600°F. POURING TIME 3 MIN.

of risers, in many cases, has been reduced to a point where they serve more as whistlers or vents than as feeding heads.

25. Where exceptionally heavy sections occur, the neck type riser is used. This consists of a large, heavy riser placed over a dry sand core which contains the small neck.

26. After the casting has been poured in the regular manner, hot feed iron is poured into these large risers as required, to allow normal feeding to take place.

27. Excellent results have been obtained with this type of riser. The core containing the riser neck becomes incandescent during the pouring operation, preventing the neck from freezing and allowing feeding to continue. These risers are easily broken from the casting, leaving only the small necks to be chipped. There is no evidence of shrinkage defects under these risers, and casting sections are sound and close grained after machining.

28. Substantial savings have been made in our cleaning costs as a result of these changes.

VENTING

29. More trouble can be caused by improper venting than is

generally realized. The bottoms of our pits are made up with a coke bed from 4- to 6-in. deep, and good sized vent pipes are placed along the sides, spaced about 6 ft. apart. One end of the pipes rests on the coke bed and the other end protrudes from the top of the pit to permit rapid escape of the gases generated when pouring the mold. When the pit is quite deep, a secondary coke bed is provided around the pattern, about half way to the top, with additional vent pipes properly placed.

30. During the ramming operation, suitable provision is made for connections with the core prints on the pattern, so that the gases from the cores can have ready access to the open air outside the mold.

31. Cores are made with maximum size vents permissible. Cast iron arbors are used for reinforcing the sands, generous coke beds are provided in the centers for venting and suitable hooks are used to permit safe handling with the cranes.

32. With proper permeability of the sand, thorough drying and careful attention to venting, the terrible hazard created when a big casting blows can be reduced to a minimum and even eliminated entirely.

CUPOLA OPERATION

33. Three cupolas, with a total melting capacity of 45 tons per hour, are available. One or more are operated daily to meet tonnage requirements.

34. Metal is melted at 2800°F. (1538°C.) or over, with temperature readings taken and recorded at the spout. A close control is maintained throughout the heat. Chill tests are made from each ladle of iron as tapped, so that corrections may be made, as desired. Test bars are poured from each mixture melted and also to meet customer specifications. Ladles vary in size from 2 to 30 ton capacity. When filled with molten metal, the slag is skimmed off, and the ladles are moved to the pouring stations with a minimum loss of time.

POURING

35. Castings are poured at temperatures ranging from 2500° to 2700°F. (1371° to 1482°C.). The desired pouring temperature for each casting is predetermined and indicated on the daily heat sheet. When the ladles reach the job, pyrometer readings are taken

again so that the pouring temperature may be closely controlled to conform with that predetermined for each casting.

36. The total gating area, the number of ladles used, the metal temperature and the skill with which the ladles are handled will govern and control the pouring speed.

37. Our pouring speeds are regulated to deliver hot metal into pit molds at a rate of 10 to 15 tons per min. We provide and make use of suitable flow-offs, wherever possible.

SHAKE-OUT AND CLEANING

38. Depending on size and weight, castings are allowed to cool in their pits or flasks for various lengths of time, ranging from one day to 3 weeks. After this cooling period, they are removed from the sand and delivered to the cleaning department.

39. Very little sand adheres to the castings when removed from the flasks or pits, and it is easily removed with a wire brush, or broom. The cores are readily removed, due to the easy collapsibility of the sand, and a clean smooth finish is obtained on the inside and outside surfaces of the castings.

40. Since this core sand is identically the same as the molding sand, it is returned from the cleaning department to the sand storage pit. All sand removed from the pits and all shake-out sand from the flasks is dumped into the storage pit. From the storage pit, the sand passes through the reclamation unit and reenters the system. No sandblasting is required on these castings.

STANDARD PROCEDURE

41. Before starting work on any large casting, a certain amount of engineering and planning is necessary to determine the proper method of procedure. The drawing is carefully checked and special consideration given to the following details:

42. *Dimensions*: To determine the proper size pit or flask required; whether available or necessary to build.

43. *Type of Casting*: To check physical properties required and to determine suitable metal mixtures to meet specifications.

44. *Design:* Finished surfaces and pressure areas.
Possibility and prevention of shrinks, cracks and distortion.
The most practical and economical method of production.
Insuring means to vent mold and cores.
Proper securing of cores.

Means of removing cores and arbors.

Method of handling casting after poured.

45. *Metal Thickness:* To estimate weight of casting.

To estimate amount of metal required to pour.

To determine size, number and location of ingates and downgates.

To determine size, number and location of risers, whistlers and flow-offs.

To determine size and location of chaplets.

46. *Other information* considered at this time includes: Method of drying and time required.

Securing and blocking of the mold or pit and total weight required on copes when pouring to overcome static pressure.

Pouring temperature.

Stripping, cooling time required and shake-out.

47. The drawing is then properly marked to indicate the planned procedure, and a job instruction sheet is prepared listing all detailed information accordingly. Copies of this instruction sheet are issued for the guidance of the foremen assigned to the job.

SUMMARY

48. To summarize, modern methods can be and are being successfully applied to produce large, heavy castings. These methods can be standardized and controlled with profitable results.

49. Synthetic sand is being successfully applied to produce heavy castings weighing up to 125 tons. These castings have clean smooth surfaces, inside and outside. Dimensions are true to pattern. Metal structures are sound and dense. Considerable savings can be effected in material, labor and cleaning costs. The use of one facing sand mixture for molds and cores alike simplifies production and promotes economy.

50. One grade of high quality blacking, properly prepared and controlled, can be used on all molds and cores. This eliminates individual tampering and offers a method that is fool-proof and economical.

51. The use of portable mold dryers, delivering a constant supply of hot, dry air, under pressure, at uniform temperatures, has proven that drying time and costs can be substantially reduced.

52. With proper gating, it is possible and preferable to pour heavy castings at elevated temperatures and at controlled speeds.

By pouring at elevated temperatures, the size of risers can be reduced, many risers can be eliminated and the use of feeding rods is unnecessary.

53. Careful attention to venting of the mold and cores will minimize or eliminate the dangers created when a casting blows while being poured.

54. Proper securing and blocking of the flask or pit and sufficient weights on the copes when pouring are absolutely essential to insure a good casting, by preventing strains, run-outs or both.

55. Metal melted at 2800°F. (1538°C.) or over can be held in large ladles so that molds may be poured rapidly at temperatures of 2500° to 2700°F. (1371° to 1482°C.).

56. Suitable metal mixtures, good cupola practice and hot pouring will provide heavy castings with improved physical properties.

57. The application of modern controlled methods will produce heavy gray iron castings with clean, sound, close grained metal sections that will meet the specifications and approval of the customer.

DISCUSSION

Presiding: M. J. GREGORY, Caterpillar Tractor Co., Peoria, Ill.

W. L. CHATFIELD[1]: What are the metal specifications on your heavy castings? Are they different on the 16 and the 30 ton?

MR. APPELBY: That depends upon the type of casting and the purpose for which it is used.

MR. CHATFIELD: The machine tool castings, for instance.

MR. APPELBY: Our metals generally contain total carbons ranging from 2.90 to 3.50 per cent. For the particular machine tool castings pictured here the total carbon runs from 3.00 to 3.10 per cent, the silicon 1.50 to 1.75 per cent, tensile strength from 35,000 to 40,000 lb. per sq. in. The metal mixture contains from 30 to 35 per cent steel, although one of the castings pictured here contains 60 per cent steel in the mix.

MR. CHATFIELD: You showed a picture of a 32-ft. lathe bed. How much of a dip do you use on such a lathe bed to make it come straight?

MR. APPELBY: Three-quarter inch.

MR. CHATFIELD: What percentage of steel do you use in your iron mixture? We use 60 per cent steel in our lathe beds, and on 20-ft. beds we dip them ¾-in.

MR. APPELBY: Our mixture is from 35 to 40 per cent steel.

A. LEBESCH[2]: On the riser appearing on that section of the casting, I presume you have a core underneath the head. If so, how heavy is the core?

MR. APPELBY: One and one-quarter inches thick.

MR. LEBESCH: Is that a standard size?

MR. APPELBY: The thickness is standard, but we have several sizes for the square area. The surface to be covered determines the size core used. The core used on this casting was 16-in. sq., 1¼-in. thick, with a 2-in. diameter hole in the center, to form the riser neck.

MR. LEBESCH: What is the dry bond in that particular core?

MR. APPELBY: The dry compression strength is 200 lb.

MR. LEBESCH: You say that you dried the frame in 24 hr., using gas and air? Was it circulating through one end of the mold?

MR. APPELBY: Using a mixture of gas and air, our portable heater blows the heat into one end of the pit and exhausts through properly located vents in the opposite end. The heat is circulated under pressure.

J. A. MURPHY[3]: Is there any particular reason for using the enormous amount of weight on that big mold in the floor?

MR. APPELBY: We do such a large variety of work that we find it a lot easier to use weights, rather than make special pits and provision for bolting down the copes. We may run a pit for a month or two on a certain job and then find it necessary to fill in for use as floor space. We have the weights available and find it a simple and economical method for securing copes.

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[1] Fate-Root-Heath Co., Plymouth, Ohio.
[2] Allis-Chalmers Mfg. Co., Milwaukee, Wisc.
[3] James A. Murphy and Co., Hamilton, Ohio.

MR. MURPHY: I do not mean to criticize but, personally, I have never considered weights as safe or scientific; I have seen too many losses from them.

MR. APPELBY: Why?

MR. MURPHY: There have been a few occasions when I have turned 200 or 300 tons of weights into scrap, which is a lot better than can be bought. It is bad to have that much money tied up around the foundry, particularly at the present time.

MR. APPELBY: I am sorry, I cannot agree with you. I claim that you can definitely determine how much weight is required for every job. No guesswork is necessary.

MR. MURPHY: There are some things which cannot be figured exactly. Sometimes the speed of pouring depends on the temperature, the amount of surface and the velocity. It leaves too much to the imagination.

MR. APPELBY: The important thing to consider is the static pressure involved. I figure the amount of weights required to hold down a cope by the static pressure. The formula is quite simple. For example, if you have a cope area of, say, 200 cu. ft., in order to overcome that pressure you should have at least 50 tons of weight to hold down the cope. I like to pile on 25 to 30 per cent more, if possible, as a safety factor.

MEMBER: I would like to know what rule shrinkage you use for the patterns.

MR. APPELBY: A 1/10 or 1/12 in. per ft., depending upon size of the casting.

R. E. LONG[4]: I would like to know if there is any definite relation between the risers on the machine tool casting, for instance, and the weight of the casting, and if there is any definite ratio between the neck of the riser and the riser itself.

MR. APPELBY: The size of the risers has no relation to the weight of the casting. All I am concerned about is the metal thickness or cross section.

MR. LONG: How did you determine, on the one casting, that you were going to use a 12-in. diameter riser? Why was this used, instead of a 14-in. or some other size riser?

MR. APPELBY: I started with an 8-in. riser and found shrinks. The correct size to eliminate shrinks was determined by experiment.

MR. LONG: How about the relationship of the 2 to 12 (neck diameter to riser diameter)?

MR. APPELBY: This was also determined by experiment, after starting with a 12-in. riser and 4-in. neck, which produced shrinks.

MR. LONG: Would you say that the 1 to 6 ratio can be safely used?

MR. APPELBY: No, I would not.

MR. LONG: If you made another casting that would require a 6-in. diameter riser, would you put a 1-in. neck in that?

MR. APPELBY: I would if I were using a 6-in. riser.

MR. LONG: Is that ratio approximately correct?

MR. APPELBY: It is approximately correct, but I would not vouch for

[4] Hardinge Manufacturing Co., York, Pa.

it as a general rule. On this particular casting, I started with a 4-in. neck and found shrinks under the riser. I cut the neck down to 3-in., and while there was a little improvement, there was still evidence of shrinkage. When the neck was reduced to 2-in., there was no shrink under the riser, and after machining the metal was clean and close grained. Therefore, the 12-in. riser with a 2-in. neck has been standardized for this particular casting, and we have made many of these castings without any evidence of shrinkage.

MR. LONG: Can you tell me, roughly, what the mixture of your synthetic foundry facing is on those heavy castings.

MR. APPELBY: The specifications will give you this information; namely, the facing sand permeability runs from 120 to 130, the green compression strength is 8 to 9 lb., moisture content 6 to 6.5 per cent and dry compression strength 160 to 180 lb. The heap sand permeability runs from 120 to 130, green compression strength is 6 to 7 lb., and dry compression strength 100 lb.

The reclaimed sand from our system is the base from which all facing and heap sand are prepared. To prepare facing sand we add new sand, compounds and water. To prepare heap sand we add water only, since there is enough bond retained in the reclaimed sand to give us the required strength. Every lb. of sand used in our foundry is mulled.

MR. LONG: Do you mind giving us the formula?

MR. APPELBY: We run 1000-lb. batches of sand in no. 2 mixers. Our facing sand mixture consists of: 1000 lb. reclaimed sand, 25 lb. silica sand, 16 lb. clay binder, 5 lb. pitch compound, 7 gal. water. To prepare special sand for ingate, downgate and riser cores, we add 6 lb. of straight pitch to the above mixture.

MR. LONG: What is the compression strength on the sand for gates and risers?

MR. APPELBY: The green compression strength is 10 lb. and the dry compression strength is 200 lb.

G. E. LARSEN[5]: Are you troubled with any cinders from the compound used in that facing in your sand heap?

MR. APPELBY: If you mean cinders that might be formed from the pitch, due to a coking condition—no, we have not encountered that.

MEMBER: Of what does your reclaiming unit consist?

MR. APPELBY: The reclamation unit consists of: shake-out grille and hopper, vibrator, conveyor, magnetic separator, breaker barrel, discharge pit, elevator, sorting screens, discharge spout and several 10-ton capacity receiving tanks. Dust pipes are connected at each point of operation throughout the system, and fines removal is controlled by regulating the dampers in these pipes.

MEMBER: You have no hummer screens?

MR. APPELBY: There is a hummer screen in the system for sorting sand, coke, pieces of brick, or any refuse which will not pass through the final 3/16-in. mesh screen.

MR. MURPHY: There is one thing connected with the manufacture of heavy castings which will probably bear discussion. You showed one

[5] Central Utah Vocational School, Provo, Utah.

casting there, a half round casting. There was a multiplicity of risers on it, and you cut off some of them. I just want to bring up the question that one riser is better, positively better, than a multiplicity, providing there is an even thickness.

MR. APPELBY: I agree with you 100 per cent. That is the point I tried to bring out in describing this casting—that we now have four large, heavy risers across the face at the joint, and five small risers on the rails. There is now a total of nine risers against the former practice of using 28 risers.

MR. MURPHY: I have poured castings of 100 tons with one riser sufficiently large, and I never found any shrinkage from any of the risers.

A. J. DUBLO[6]: This hot pouring interests me greatly. You gave the total capacity of the cupola as 45 tons per hr. Supposing you use one or more; that would figure that the 130 ton casting poured would take about 3 hours to melt.

MR. APPELBY: It takes longer than that—about 5 hours, using two cupolas.

MR. DUBLO: What do you do to keep that 2800° iron from getting cold?

MR. APPELBY: We keep the metal in the ladles covered with charcoal screenings. On that particular casting, the 100 ton anvil block, we are very lucky to approach a pouring temperature of 2600°, but we do not drop below 2500°.

MR. DUBLO: On this high pouring temperature, do you take microstructures of your metal? If so, have you noticed any difference in the microstructure when you poured hot and when you poured cold, possibly a detrimental difference?

MR. APPELBY: It so happens that our metallurgist, W. H. Rother, is in the audience. He can answer that question.

W. H. ROTHER[7]: The castings poured at the higher temperature would have a finer grain structure than the castings poured at the lower temperature.

MEMBER: Mr. Appelby, you stated that, when pits are quite deep, you add an auxiliary coke bed. What would you call "quite deep"—6, 7 or 8 ft?

MR. APPELBY: The particular pit used for the engine frame casting is 10 ft. deep. The casting is 8 ft. 6-in. deep. We go up 5 ft. from the bottom of the pattern and place the secondary coke bed. Answering your question as to what I consider a deep pit, that is more or less a matter of judgment. If I had a pit 5 ft. deep, or possibly 6 ft., I would consider one bed of coke in the bottom to be sufficient. But when we get down to 7 ft. or deeper, I like to put in a secondary bed of coke. It can do no harm, and may do a lot of good. I like to get the gas out of the mold just as fast as possible.

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[6] Sterling Foundry Co., Wellington, Ohio.
[7] Buffalo Foundry & Machine Co., Buffalo, N. Y.

MEMBER: You were asked how you kept the temperature up if you took 3 to 3½ hr. to melt your metal. Do you find any solidification in the bottom of the ladle?

MR. APPELBY: We certainly do, at times.

K. G. PRESSER[8]: Is there any correct method for predetermining the best pouring temperature on those large castings?

MR. APPELBY: That depends upon your own opinion and judgment. Personally, I like to pour everything as close to 2700° as possible, but, unfortunately, on these big castings we cannot always reach that degree, because we have to hold the metal too long. I set 2500° as a minimum pouring temperature and 2700° as maximum.

MR. PRESSER: You say it is a synthetic sand. What do you use as your base, a silica sand?

MR. APPELBY: The reclaimed sand from the shake-out.

MR. PRESSER: What is that original sand?

MR. APPELBY: Originally that sand consisted of a conglomerate mixture of natural molding sands, including gravels and sharp sands. When we started to reclaim the sand, we simply gathered up all the sand in the shop and put it into one central storage pit. Our records show that our sand reclamation is about 98 per cent effective.

MR. PRESSER: What do you add to make it 100 per cent effective?

MR. APPELBY: Washed and dried silica sand of 33 A.F.A. fineness.

C. GREEN[9]: What is the clay content of your facing?

MR. APPELBY: Approximately 10 per cent.

MR. GREEN: On the large molds, where the finishing time is more than a couple of hr., do you have any trouble with the sand drying out?

MR. APPELBY: Yes, it is necessary to move fast. Where we cannot finish the job on the same day that the pattern is withdrawn from the sand, we cover the face with wet bags, and then continue the next day. That is one of the problems with synthetic sand; it will dry out very quickly.

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[8] National Supply Co., Springfield, Ohio.
[9] Sarbo Mat Process Engineers, St. Louis, Mo.

Present Status of the Side-Blow Converter

By A. W. Gregg*, Harvey, Ill., and F. B. Skeates**, Chicago, Ill.

Introduction

1. Since July 1940, 45 new converters have been put into operation in the United States and Latin America. Thirty-nine of these converters were installed in the United States and the remaining six in Latin America.

2. A recent survey, which is believed to be reasonably accurate, shows 66 operating converters in the United States and Canada located in 37 different foundries. These figures include converters which have been in operation for years, and also idle converters which have now been put into service either in the original plant or in another foundry. There are six new converters in operation in Latin America in addition to two which have been in operation for some time.

3. Just as a matter of interest, one 2-ton converter was shipped to Switzerland and delivered prior to the fall of France. One 1-ton vessel was shipped to China over the Burma Road before it was closed, and one 3-ton vessel, which was built for the Sino Java Co., Dutch East Indies, was diverted to domestic use, because the Japanese had captured New Guinea before it could be shipped.

Increased Use in Great Britain

4. No exact data are available concerning the number of converters in operation in Great Britain, but the following quotations from two recent letters received from G. M. Menzies, North British Steel Foundry, Ltd., Balbardie Steel Works, Scotland, throws some light on the present status of the side-blow converter in the British Isles. We quote:

> "You would really be astonished at the progress converters are making in this part of the World. I would not be surprised if two-thirds of the steel castings now being made, were being made by the Tropenas Converter. Quite a number of firms have

* Whiting Corp.
** Link Belt Co.
Note: This paper was presented at a Steel Foundry Practice Session of the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1943.

thrown out large Siemens Furnaces and put in 3- to 4-ton converters."

and from another letter:

"We in this Country have been greatly increasing the percentage of steel produced by the converter, and we feel sure that if Americans had realized the difference which desulphurization and the control of non-metallic inclusions have made to converter steel, they would have been increasing the number of converters many years ago."

TENDENCY TOWARD LARGER CONVERTERS

5. For many years, the converters in use in the foundries of America were of either 1- or 2-ton capacity. There is a definite tendency today toward converters of larger capacity. Thirteen 3-ton converters are now in use, one of 5-ton and four of 6-ton ca-

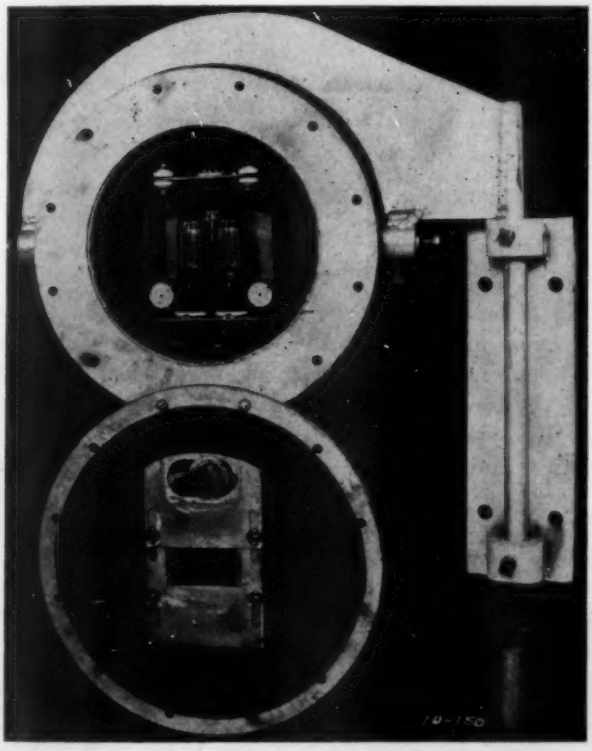

FIG. 1—PHOTOCELL UNIT (ELECTRIC EYE) FOR STEEL CONVERTER FLAME CONTROL.

FIG. 2—PHOTOCELL UNIT (UPPER LEFT) USED TO CONTROL OPERATION OF 1-TON CONVERTER.

pacity. These larger converters blow as rapidly as the smaller vessels.

IMPORTANCE OF ELECTRIC EYE CONTROL

6. One of the most important factors in the renewed interest in converters was undoubtedly due to improved control equipment. Jones & Laughlin Steel Co., after six years of intensive research, perfected the electric eye equipment (Figs. 1, 2) for control of the Bessemer operation. This development, announced about 1938, was the first and only basic improvement for control of the converter operation since Bessemer and Kelly invented the process nearly 100 years ago.

7. The equipment for control of the bottom-blow Bessemers required some modification before it was satisfactory in connection with side-blow converter operation. It has now been redesigned and is performing an outstanding service. Twenty-three complete electric eye installations have been made in 17 different foundries during the last year. They have proved to be valuable in controlling composition, reducing blowing loss (Figs. 3, 4, 5, 6), in some cases by 25 per cent and more, and increasing furnace lining life.

The electric eye determines the end point with greater accuracy and certainty than is possible with the human eye—a notoriously poor optical instrument. It is interesting to note that, in two foundries, women are being used to blow steel with the aid of electric eye equipment. Royalty payments for the use of electric eye equipment have not been required since April 1, 1943.

RECENT IMPROVEMENTS IN CONTROL EQUIPMENT

8. The converters built today are much improved in appearance and construction. The tilting mechanism has been redesigned, and is much more sturdy and dependable. The regulation of blast pressure during the blow is now controlled by motor-operated butterfly valves operated by a controller located in the operator's pulpit (Fig. 3). For convenience in tilting the vessel, while the

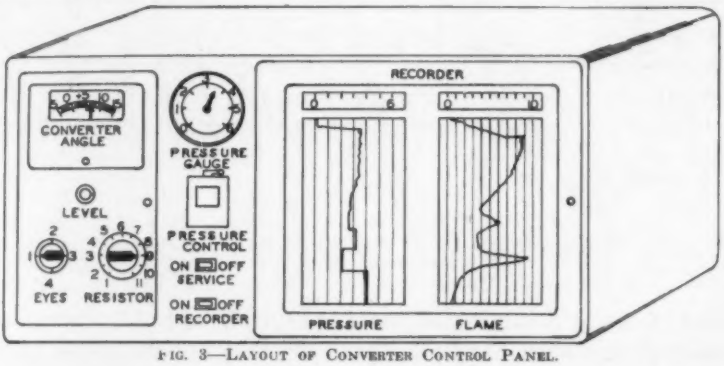

FIG. 3—LAYOUT OF CONVERTER CONTROL PANEL.

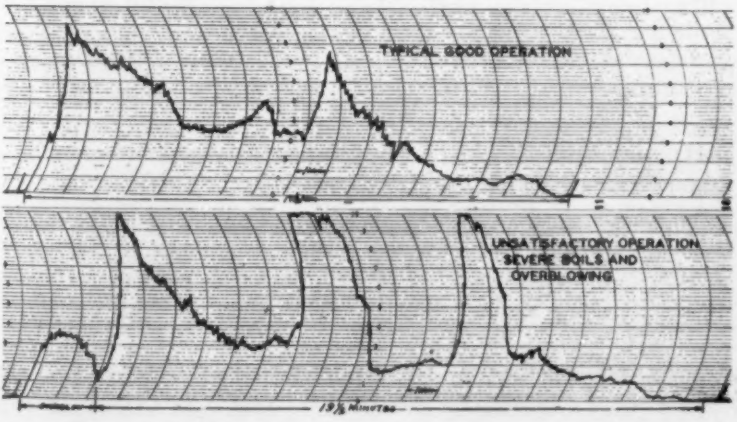

FIG. 4—TYPICAL CHART SHOWING GOOD AND UNSATISFACTORY CONVERTER OPERATION.

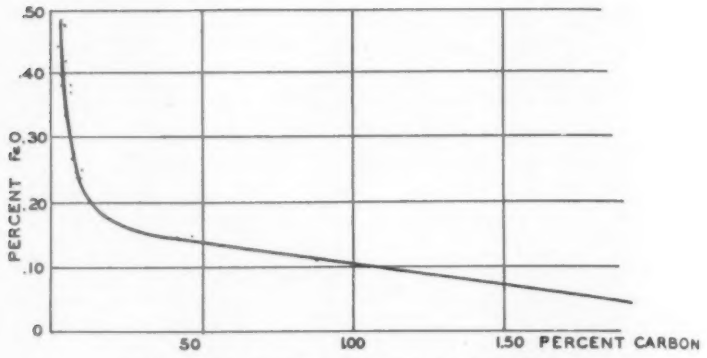

FIG. 5—RELATIONSHIP OF CARBON AND IRON OXIDE.

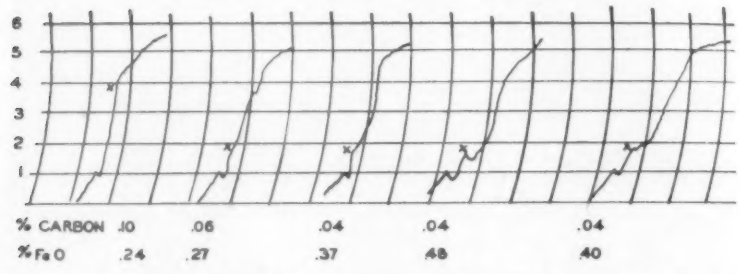

FIG. 6—CARBON AND DISSOLVED FeO IN RELATION TO TURNDOWN POINT. "X" MARKS THE POINT WHERE VESSEL WAS TURNED DOWN.

level of the bath is being adjusted to coincide with the tuyere level, an auxiliary push button pendant switch has been added to the tilting motor control. The helper holds this switch in his hand while looking through the tuyeres in order to make the proper adjustment of the bath level and the blowing angle. This makes it unnecessary to signal the man in the blowing stand to tilt the vessel to the proper angle. Another recent improvement is the electric indicator for the blowing angle. This is recorded on a dial located in the blowing stand.

9. In one large converter foundry, air weight control equipment has been installed for the blowers supplying air to the converters. This equipment has proved its worth very decidedly and we expect to see further installations in the near future.

DESULPHURIZING AND DEPHOSPHORIZING PRACTICE

10. Desulphurizing is now on an established basis, and practically all converter foundries are producing steel with 0.04 per

cent or less sulphur content. Several foundries report results averaging well under 0.03 per cent sulphur, and at least one shop is producing steel with less than 0.025 per cent sulphur, using only 20 lb. of soda ash per ton. In this particular case, cupola practice and quality of coke are excellent, and the sulphur in the cupola metal, as tapped, is under 0.10 per cent. The usual reagent for desulphurizing is soda ash or caustic soda, the latter being somewhat more efficient. One foundry is experimenting with calcium carbide, which is said to have promise.

11. Dephosphorizing for converter steel is not in the same satisfactory condition as desulphurizing. All manufacturers of acid steel, by whatever process, are in some trouble with respect to phosphorus. Several methods for removing phosphorus have been proposed as follows:

1. *The Yocom Method,* which is being successfully used at the Wheeling Steel Company, consists of a ladle treatment of the metal with a mixture of calcium oxide, iron oxide and fluorspar. Phosphorus is regularly reduced from about 0.10 per cent to 0.03 per cent or less. This method has the disadvantages that considerable temperature is lost, and that the metal is left in an oxidized condition satisfactory for the production of ingots but not satisfactory for the production of castings without further treatment. Mr. Yocom prefers to dephosphorize a heat of 5 tons or more.

2. *A Modification of the Yocom Method* has been developed in Canada by M. J. Uty, of the Chromium Mining & Smelting Corp. The principal difference between this and the Yocum method lies in the fact that the mixture is exothermic, and has been reported as having been successfully applied to as small a quantity as 500 lb.

3. *Dephosphorizing in the Cupola.* At the Ford Motor Co., G. Vennerholm has successfully dephosphorized metal in the cupola by using a basic lining and a basic slag. The method, to date, has been carried out in an experimental manner only, but if it is possible to establish it on a commercial basis, it will prove a great boon for the casting industry.

12. Phosphorus can be removed by further treatment in a basic-lined electric furnace to any required percentage, as is accomplished in one method of the triplexing process.

CONTINUOUS POURING THROUGH TRIPLEXING

13. The triplexing process, which involves the use of the cupola, converter, and electric furnace, has been adopted by nine different companies. This process has been one of the important factors contributing to renewed interest in the side-blow converter. It makes possible, for the first time in the steel foundry, the advantages of continuous pouring, resulting in large savings in labor and floor space. There are several variations of the triplexing process, the most popular of which employs an acid-lined electric furnace in which about a ½ hr. supply of steel is held constantly. The metal is finished in the ladle after the converter operation, and delivered to the electric furnace, which serves principally as a heated distributing ladle.

14. In some triplexing installations, the electric furnace will have a basic lining for finishing and dephosphorizing the steel. In this practice the operation cannot be continuous, because the electric furnace must be operated as a batch unit.

15. An acid-lined electric furnace must be operated as a batch unit if the converter steel is delivered to it in an oxidized condition, such as results from a ladle treatment for removal of phosphorus.

16. When low-phosphorus scrap is available, the most economical triplex operation will employ the acid-lined electric furnace, operated continuously on finished converter metal. The output for the electric furnace is tremendously increased as compared to cold melt operation. Fifteen tons of converter steel per hr. can be put through an electric furnace as compared to 3 tons per hr. when charged with cold stock.

17. With long hours of operation (sometimes as much as 24 hr. per day) it has become a popular practice to change shells when the lining is no longer fit for use. With good handling facilities it is possible to change shells in about an hour. Thirty spare shells have been installed in the last two years (10 different companies).

CONVERTER LININGS

18. Much study and attention has recently been given to different refractories and different methods of installing linings, in order to improve lining life. Converters are generally lined with either silica brick, ganister monolithic linings, or various combinations of brick and ganister. Proper drying, prior to preheating, is the most vital factor in securing good lining life. At one time 25 blows on a lining was considered a good performance. Records are

available today of as many as 60 blows on a lining without patching, and we have heard of one record of 80 blows. The shop not accustomed to monolithic linings will perhaps do well to commence operations with a brick lining.

19. If a monolithic lining is properly installed, carefully dried and slowly preheated, it is the most economical, and probably the most popular. Tuyeres can be formed by ramming ganister around pipes of the proper size, or brick tuyeres can be employed.

20. Whatever method is employed, it is most important to maintain the converter lining in good condition, because lowest blowing losses and most uniform operating conditions are thereby insured.

QUALITY OF CONVERTER STEEL FIRMLY ESTABLISHED

21. The Sims-Dahle report[1] quite definitely proved that the quality of converter steel is equal to that made by the open-hearth or electric furnace process at ordinary and sub-zero temperatures. This report was submitted at the June 1942 meeting of the American Society for Testing Materials at Atlantic City. Nitrogen content was shown to be as low and resistance to impact at sub-zero temperatures equal to steels made by other processes. The specification for Ordnance castings QQS-681-B, failed to include the converter as an approved process, but this specification is now being revised to put the converter on an equal basis with other processes (app.).

22. Sims-Dahle carried out the following tests:

1. Complete chemical analysis, including residuals and nitrogen.

2. Microscopic analysis to determine grain size and type of inclusions.

3. Determination of mechanical properties at room temperature as normalized and as normalized and drawn. These determinations included the usual four results from the static tension test, plus Brinell Hardness, grain size determination, and impact strength, both Charpy and Izod.

4. Low temperature notch impact tests (Charpy). Starting at 212°F., the steels were tested at the following temperatures: 212°F., 70°F., 32°F., 0°F., –20°F., –40°F., –60°F., and –80°F. By recording maximum and minimum results at each tempera-

1 *"Comparative Quality of Converter Cast Steel,"* PROCEEDINGS, American Society for Testing Materials, vol. 42, pp. 532-550 (1942).

ture the temper embrittlement point was determined. By plotting curves, this point was definitely established for each steel tested.

5. Double width Charpy bars were tested at the following temperatures, and results were compared with those for single width bars:

32°F., 0°F., –20°F., –40°F., –60°F., and –80°F.

These results confirmed those obtained with the single width bars, demonstrating the accuracy of the previous determination of the temper embrittlement point.

6. Determination of the effect of strain aging and cold working on the impact resistance of all steels.

7. Determination of fatigue properties. Two types of specimens were used, (a) the standard smooth specimen, and (b) the Kommers square-notched specimen. Steels were tested for fatigue at ordinary temperatures, and also one specimen of acid electric steel and one specimen of converter steel were tested at –40°F.

SUMMARY OF RESULTS OF SIMS-DAHLE REPORT

23. The results of these tests were summarized as follows by the authors:

1. Commercial cast steels made by six processes of melting were compared as to composition and mechanical properties. The compositions of all were normal.

2. The basic open-hearth steels had lower phosphorus contents. If the identification were to be removed from the others, it would be difficult to decide by what process they had been made.

3. The converter steels, as a group, were deoxidized with aluminum, whereas only two of the other steels were aluminum killed.

4. The microstructures were governed by the deoxidation practice, both as to inclusion type and grain size. Aluminum was the only deoxidizer that caused a definite change in type of inclusion. Titanium produced some grain refinement but not as much as aluminum.

5. The room temperature mechanical properties were entirely orthodox for grade B cast steel, and varied with the composition and type of inclusions, without regard to the method of manufacture.

6. The converter steels, as a group, had the best low-temperature notched-bar impact properties, but this is held to be a result of deoxidation with aluminum rather than melting practice.

7. The aluminum killed steels also showed less strain age hardening, which gave a fallacious advantage for the converter steels.

8. A limited number of standard fatigue tests showed a superiority in endurance ratio for the acid open-hearth and acid electric steels, but notched fatigue tests showed a notable similarity for all steels.

CONCLUSIONS

24. The conclusions drawn were as follows:

1. No evidence was found to favor one process over another, except that the basic open-hearth gave better phosphorus control. Mechanical or engineering properties of all the steels were governed by composition and by deoxidation, rather than by melting process. For example, acid electric cast steel, not having had an adequate aluminum addition, shows low-temperature impact shortcomings, just as converter steel would without an adequate aluminum addition. When low-temperature shock resistance is needed, it would be in order to impose a low-temperature notched-bar impact acceptance test. If this be done, and steel be passed or rejected on performance rather than on the melting process used, some steel now being accepted, but not of good low-temperature toughness, would be excluded, and much good converter steel would be made available.

2. With proper deoxidation, all the processes can make steel of the quality demanded for war purposes.

25. An appended report gave results of tests made on two additional steels—one made by the converter process, and one by the acid electric process. There were also some additional data, which in no way altered the results or conclusions made in the original report.

26. The conclusions drawn by the authors are very conservative and very fair. No attempt has been made to discount the quality of properly made steel produced by any of the well-known processes.

A LOOK INTO THE FUTURE

27. Further research work is now being arranged, with the

primary objects of improving lining life and decreasing blowing losses. Blowing loss is one of the largest items of cost in converter operation. Today such losses vary from 10 per cent to 16 per cent. The objective is to set up rules for operation which will make it possible to maintain blowing losses not to exceed 10 per cent. Various refractories and methods of lining will be investigated, because good lining life and low blowing loss go together.

28. When the war demand for steel castings comes to an end, the converter will have a considerable advantage over other steel producing methods because conversion cost is not so seriously affected by limited or intermittent operation. The converter can be put into operation on short notice and does not require attention, or need to be kept hot during shut-down periods.

29. As previously noted, there is a decided tendency at present to install larger side-blow converters, and we venture to predict that side-blow vessels with capacities of 10 to possibly 25 tons will find important application in steel mills and foundries. A 6-ton side-blow converter will produce as much steel as a 150-ton open-hearth furnace, and by combining several blows in one ladle it is possible to pour large castings.

30. There is also a decided interest in small side-blow converters. A 500 to 1000 lb. capacity converter is now being installed at a well-known research institute to determine the possibilities of smaller vessels. They should prove of interest to a foundry having a limited demand for steel castings, and also should find an important application in the manufacture of high-test cast irons having carbon contents intermediate between steel and cast iron.

Appendix

In a recent conversation with C. W. Briggs, Technical Director, Steel Founders Society of America, Cleveland, the following information was obtained:

"Converter steel has been definitely restored as an approved process in specification QQS-681-B. The results of the Battelle report, which were confirmed by duplicate tests at Watertown Arsenal, are responsible for this action of the Specification Committee of the Ordnance Dept."

"The American Society for Testing Materials, in June 1942, appointed a special sub-sub-committee reporting to sub-committee 22, section on castings. J. J. Kanter, of Crane Company, is Chairman of

sub-committee 22. This special sub-sub-committee is composed of the following men:

V. T. Malcolm of Chapman Valve Co., Chairman
James Ferguson, alternate for Mr. Lee Wilson of Reading Steel Co.
Sabin Crocker, of Detroit Edison Co."

"This committee presented a report on January 8, to J. J. Kanter concerning the advisability of restoring the converter as an approved process for high temperature, high pressure service. The A.S.T.M. specifications involved are A-95-41, A-216, A-217, A-157-42. The recommendation of this sub-sub-committee was to the effect that none of these specifications should be changed to restore the converter as an approved process. At the present time J. J. Kanter of Crane Co., on his own initiative, is conducting high-temperature creep tests on converter steels. No results of these tests are, as yet, available."

"With reference to the supposed difficulty in welding converter steel, further tests should be carried out immediately. Apparently, there is no evidence to support the contention that converter steel is not as readily weldable as steels made by other processes."

DISCUSSION

Presiding: H. D. PHILLIPS, Lebanon Steel Foundry Co., Lebanon, Pa.
Co-Chairman: F. A. MELMOTH, Detroit Steel Castings Co., Detroit, Mich.

JOHN HOWE HALL[1]: Mr. Gregg said that the electric eye was the first real improvement since Bessemer and Kelly invented the converter. If Mr. Gregg had ever had to run a 3-ton bottom-blow converter, trying to make small carbon steel castings, he would not make that statement. I had the misfortune of trying to run a small bottom-blow converter for carbon steel, and I can say that the invention of the side-blow converter was a tremendous improvement.

MR. GREGG: I will accept Mr. Hall's comments on the side-blow converter as compared to the bottom-blow converter. However, I think it is generally understood that I was speaking about operation, not equipment.

J. MCBROOM[2]: I would like to say a word about the electric furnace end of this triplexing. When an electric furnace is used in connection with a converter, it is often just a holding furnace, but I do not think that is triplexing. To my mind, triplexing means three distinct refining operations. Would it be called triplexing if the metal was run into a big holding ladle? I have seen an electric furnace run for an hour at a time, in a so-called triplexing operation, and the current was never turned on at all, because the converter steel was hot, the furnace was hot, and the metal was coming through hot.

There are some converter operations which, in my opinion, are defi-

[1] General Steel Castings Corp., Eddystone, Pa.
[2] Hydro-Arc Furnace Corp., LaGrange, Ill.

nite triplexing. In these cases, some refining operation, such as adjustment of slag, deoxidation, or alloying, takes place in the electric furnace.

While I have never actually operated a triplexing shop, I have never liked the idea of adding alloys in that ladle transferring metal from the converter to the electric furnace. Many people do not agree on that point, so I would like to hear some comment on it. Is it not desirable to get into a real triplexing operation, with a definitely higher alloy recovery, by putting those alloys in the electric furnace, thus using the furnace to the maximum advantage, and not merely as a holding ladle?

MR. GREGG: I once heard it said, at a meeting in Detroit, that triplexing, as practiced in many shops, was nothing but metallurgical hypocrisy. There are a lot of variations of the triplexing method. The reason for the type of operation that Mr. McBroom described is speed and a continuous supply of metal.

However, there is one installation that is now being installed to make very highly refined ingots for airplane steels. In that operation there will be a melting operation in the cupola. The metal will be blown in a converter to remove carbon, silicon and manganese. Without any additions, it is going into basic electric furnaces, where there will be a true refining operation.

This will be a true triplexing operation, but there is something to say for the acid continuous process. I have never seen an operation where they did not turn on the current, but I have seen plants put 15 tons per hr., through an acid-electric furnace and pour four, five or six molds a min. on a conveyor. Every time a converter heat was dumped into the electric furnace, temperature, as well as composition, was checked, and there was some attempt to refine, because the slag was kept as a refining slag. However, it was not very much, when there was ½ hr. supply of steel in the electric furnace and heats were being dumped from the converter just as fast as they could blow. That furnace was kept full, and they were taking the steel away in an 800-lb. ladle. Incidentally, they were making first-class castings which met any specification.

MEMBER: Is there an operation, in this country, using a basic electric furnace as the last step in triplexing?

MR. GREGG: That is the one I just mentioned, which happens to be an ingot shop. It is the only one I know of where a basic furnace is combined with the converter and the cupola in a triplexing process.

MEMBER: How much phosphorus reduction do they get?

MR. GREGG: It will depend entirely upon how much phosphorus they get in their stock, and they are going to melt pretty poor stock. They are anticipating about 0.15 per cent of phosphorus.

MR. MCBROOM: There is an operation now being set up for a basic electric furnace following a converter. In fact, it is a real quadriplex operation, the first with which I have come in contact. The cycle is cupola, converter, basic electric and acid electric. It is not yet in operation and there are no data available. However, it will be very interesting to watch how that operation develops.